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Florida Tech CubeSat Experiment Feasibility Study

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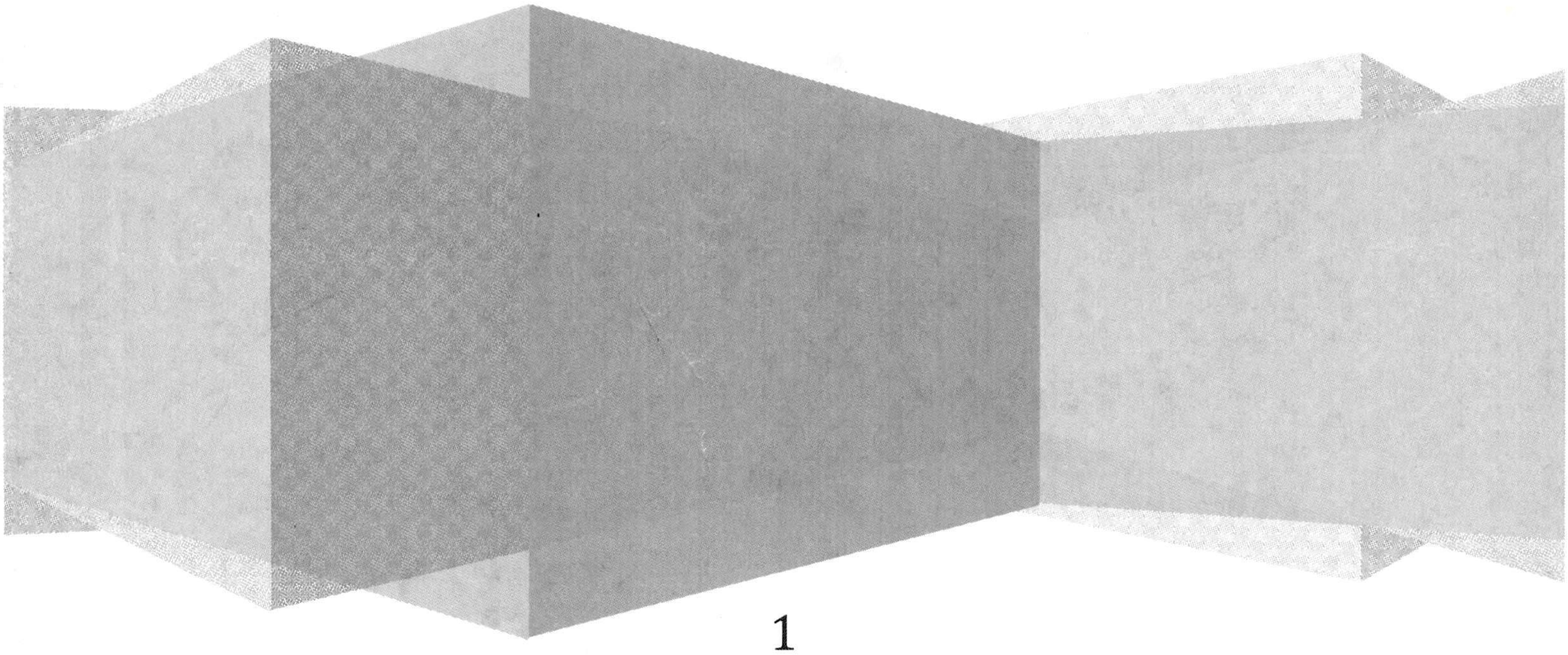

Table of Contents

List of Figures

List of Tables

List of Equations

Member	Contribution	Time (%)
Dr. William Arrasmith	Principal Investigator, Team Lead & System Engineering Analysis, Integration, Baseline Control	10
Dr. Stephane Bucaille	Requirements analysis, functional analysis, CRADLE, Configuration Control, SW&P analysis of electrical components, notional layouts, notional Imaging Sensor Component Selection for SW&P analysis	10
Dr. Razvan Rusovici	Vibrational, mechanical, shock analysis/modeling , testing and certifications, accelerometers, thermal sensors, notional sensor component selection (except imaging sensor) for SW&P analysis, CubeSat PPOD ejection analysis	10
Dr. Don Platt	Orbital modeling, communications systems feasibility, space environment, ground stations, link budgets (near low earth orbit (LEO), far LEO, and nominal track; 9 to 90 minute CubeSat launch window)	10
Todd Guidry	System Engineering student Integration lead; project coordinator; Requirements Analysis Support, Interface Control Document/Requirements Analysis, CONOPS	20
Deepika Bandar	Notional Board lay-outs for Size, Weight, and Power Feasibility, electrical systems modeling, and bandwidth analysis.	20
Everett Coots	Feasibility Report Analysis, FMEA/FMECAs, Risk Assessments, and Systems Engineering Analysis, EMI Discussion, Engine Start-up detection circuit	10
Russ Davidson	FPGA Signal processing/space systems support, report review	10
Harris SE Student Team	Independent review and SE support	10

Figure 1: Team Work Breakdown

Acknowledgements

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Introduction

CubeSats are a relatively new type of satellite. Smaller than long-term (5+ year life expectancy) satellites, these pico-satellites are comparatively cheap, small (10x10x10 cm), and are very versatile. Universities world-wide are using CubeSats to conduct a variety of experiments in space without the need for a large experimental platform.

Today CubeSats are considered to be one of the most effective ways to send a small payload into space and has attracted the attention of many educational and non-profit organizations. As this pico-satellite model continues to gain penetration into the satellite build and launch industry, it is expected that more governmental, educational, and commercial interests will emerge. As an example, more of the space-related items of high interest to the National Science Foundation may be tackled with a CubeSat platform resulting in lower life cycle costs than traditional satellite options.

NASA LSP, in cooperation with the Florida Institute of Technology, has initiated a feasibility study to investigate the technical aspects of measuring and transferring vibration, acceleration, temperature, and video data from a CubeSat to NASA Hanger AE on Cape Canaveral Air Force Station (CCAFS) a.k.a. Kennedy Space Center (KSC).

This report provides a technical feasibility analysis to determine whether-or-not a specific set of NASA/LSP requirements can be accomplished. Our approach has been to provide a "notional" component layout to determine the feasibility of the NASA/LSP stakeholder requirements. The notional layout is used to consider component level technical issues such as size, weight, & power (SWaP), bandwidth, and other critical technical parameters. Even though the notional components may satisfy the stated requirements and thereby demonstrate feasibility, the notional layout is NOT considered a design since no component optimization and design trade-off analysis has taken place. This activity should be accomplished in an appropriate design phase that is outside of the scope of this effort.

Mission Statement

It is the mission of this Florida Tech CubeSat project, in partnership with NASA/LSP and Analex Corporation, to complete a feasibility study on the CubeSat Experiment requirements issued by Analex in their request for proposal (RFP) dated 8 June, 2010 (RFP #: 10-659). This study will investigate the feasibility of the technical requirements stated in the RFP solicitation using commercially available and possibly space qualified products (if required).

Scope

The objective of this study is to evaluate the feasibility of a NASA Launch Services Program telemetry system using the CubeSat/Poly-Picosat Orbital Deployer (P-POD) platform. This platform consists of a PPOD, CubeSat experiment, and vehicle wiring harness. The CubeSat will provide the capability to store wired and wireless sensor data during specific moments before, during and after launch, stage separation, payload separation, and up to 1 minute after a Low Earth Orbit (LEO) deployment, and return data to Hanger AE at Kennedy Space Center within 24 hours of mission completion. The results of this study may be used toward developing the requirements of a CubeSat System for a future NASA mission.

CONOPS

The figure below is the Concept of Operation (CONOPS) for the CubeSat experiment that serves as the focus of our feasibility study. This image describes all of the proposed characteristics in the intended CubeSat experimental system.

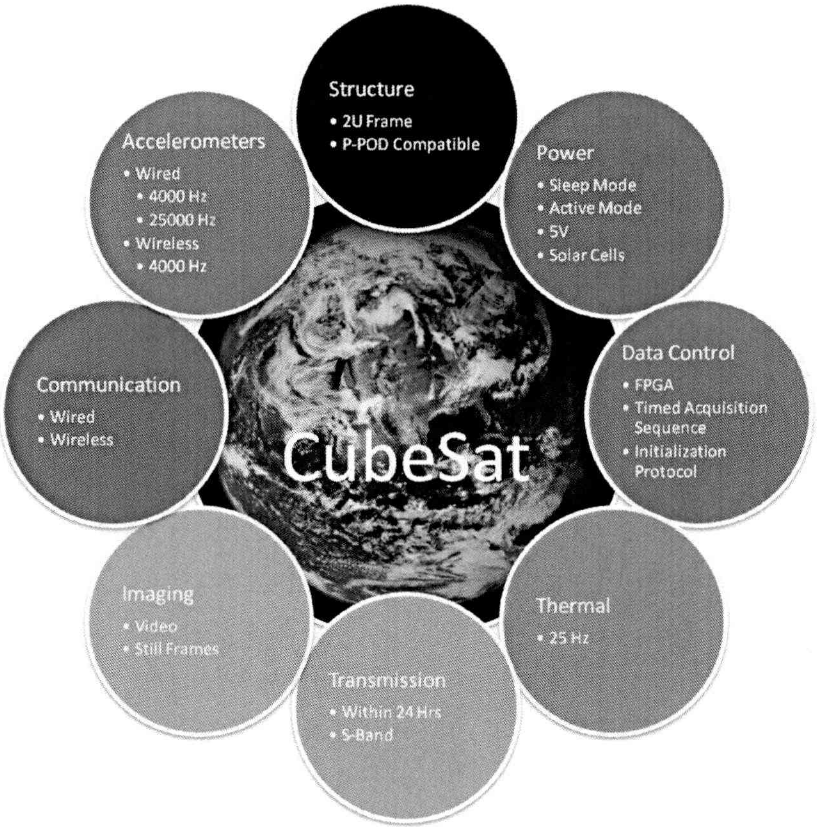
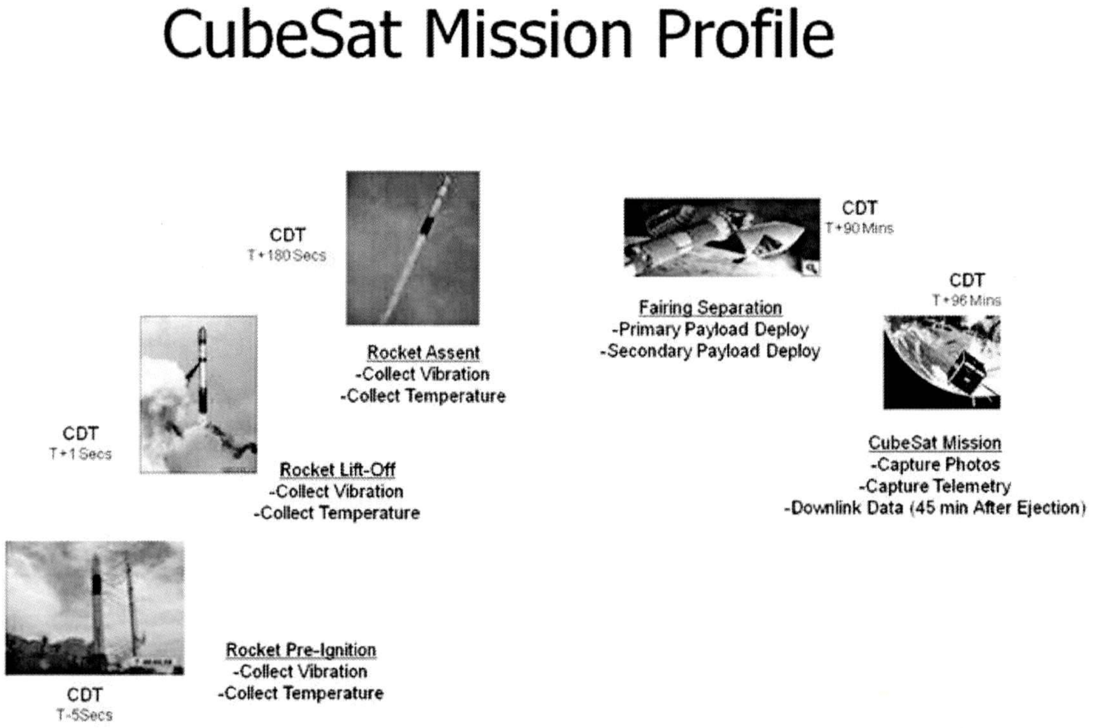


Figure 2: CubeSat CONOPS

The CubeSat experiment could be launched either from the east or west coast of the United States. The proposed experiment will consist of collecting launch data to include accelerometer data for engine start-up, wired and wireless accelerometer data during stage separations and payload separation. Accelerometer data is to be collected at 4000 samples-per second and 25000 samples-per-second according to the requirements in the Requirements Analysis section below. Temperature data is also to be collected at a rate of 25 samples per second. Finally, there is video/image data to capture separation events between the 2U and 1U CubeSats as they are ejected from the PPOD environment. All data needs to be returned to hanger AE at KSC within 24 hours of mission completion.

The CubeSat Mission Profile below illustrates the critical experimental events. It is important to note that the last opportunity to handle the CubeSat is nominally 30 days prior to launch. Additionally, CubeSat experiments should be capable of operating with launch delays up to 30 days.



CubeSat Mission Profile

CDT
T-5Secs

Rocket Pre-Ignition
-Collect Vibration
-Collect Temperature

CDT
T+1 Secs

Rocket Lift-Off
-Collect Vibration
-Collect Temperature

CDT
T+180 Secs

Rocket Assent
-Collect Vibration
-Collect Temperature

CDT
T+90 Mins

Fairing Separation
-Primary Payload Deploy
-Secondary Payload Deploy

CDT
T+96 Mins

CubeSat Mission
-Capture Photos
-Capture Telemetry
-Downlink Data (45 min After Ejection)

Figure 3: CubeSat Mission Profile

The first recordable event should be the accelerometer and temperature data capturing the engine start. Two sets of three orthogonal axis wired accelerometer data are collected on the 2U CubeSat at 4000 samples-per-second for each channel and 25000 samples per second for each channel respectively. The data collect start time is given by the Countdown Time (CDT) of five seconds prior to launch (T-5 Seconds) shown at the far left of the CubeSat Mission Profile figure below. Temperature data is collected at sample rates up to 25 Hz (nominally 1 to 2 samples per second based on subsequent discussions with NASA/LSP and Analex). During Rocket Lift-Off, these data are collected through a CDT of T+1 Seconds.

During the rocket assent portion of the CubeSat experiment, accelerometer and temperature data should be collected according to the CubeSat mission profile. The wireless accelerometers are placed on a 1U CubeSat and should collect 3-orthogonal axis accelerometer data at 4000 samples-per-second and transmit this data to the adjacent 2U CubeSat. Additionally, 3-orthogonal axis accelerometer data should be collected in a wired configuration at 4000 samples-per-second for each channel and also at 25000 samples per second for each channel during these events. Temperature data should be collected at 25 samples per second. The temperature data collect requirement was relaxed subsequent to the issuance of the NASA/Analex RFP and was reduced to 1 sample every one to two seconds for all collected temperature data.

Similar data is to be collected for the fairing separation and payload deployments and also for the CubeSat ejection from the PPOD. Also, image data should be captured as the CubeSats (1U and 2U) are ejected from the PPOD up to 1 minute after deployment. All mission data is down-linked and returned to Kennedy Space Center Hanger AE starting 45 minutes after ejection from the P-POD and within 24 hours after CubeSat mission completion.

Stakeholders

For a project to be successful, it is important for the team to understand the requirements imposed by each stakeholder. In doing so, the analytical team should conduct studies on how feasible each requirement is, along with a realization of what negative consequences could occur if these requirements are not met.

For the purpose of this study the main stakeholder, NASA LSP, will be the primary stakeholder. The Analex Corporation, as NASA/LSP's technical advisory group, is also considered to be a stakeholder in this process. Based on stakeholder input, only technical feasibility will be covered. That is, organizational feasibility, managerial feasibility, political feasibility, and economic feasibility considerations are not addressed in this study.

Requirements Analysis

The Analex RFP defines eight technical requirements that must be evaluated for the requested feasibility study. Commercially available space qualified items, non-space qualified equivalent parts, and space ready commercial-off-the-shelf (COTS) items were reviewed and evaluated as part of this study. A system engineering approach was adopted in conducting this feasibility analysis and a requirements analysis, functional analysis, and complementary risk analysis was conducted as part of this effort. From the feasibility to initiate the CubeSats power system to the physical structure of the CubeSat, all critical CubeSat systems and functions are addressed. A complete list of the NASA/LSP requirements – as articulated in the Analex Corporation RFP – is presented below:

1. The system shall conform to the most recent "LSP CubeSat to P-POD Interface Control Document for NASA Kennedy Space Center Launch Services Programs."

2. The system shall have a 2U CubeSat (twice the size of a standard CubeSat) mass of 2.0 kg.

3. The system shall be capable of acquiring and storing wireless accelerometer data in three (3) mutually orthogonal axes where data is acquired and stored within the System 2U CubeSat and accelerometers are located within adjacent 1U CubeSat, acquiring data at a minimum acquisition sample rate of 4000 Hz from T-0 through 1 minute following CubeSat ejection from PPOD.

4. The system shall be capable of acquiring and storing two (2) separate sets of wired accelerometer data in three (3) mutually orthogonal axes where accelerometers are located within the System CubeSat, at a minimum acquisition sample rate of 4000 Hz and 25,000 Hz for each set respectively, from 5 seconds prior to T-0 through 1 minute following CubeSat ejection from PPOD.

5. The system shall be capable of acquiring and storing video camera data from a camera that is located within the System CubeSat, is oriented longitudinal to the PPOD ejection plane, and is capable of acquiring video of adjacent CubeSat from 5 seconds prior to CubeSat ejection through 1 minute following CubeSat ejection.

6. The system shall be capable of acquiring and storing wired thermocouple/RTD data within the System CubeSat at a minimum acquisition sample rate of 25 Hz from 5 seconds before T-0 through 1 minute following CubeSat ejection from PPOD. Note: This was later relaxed during discussions with NASA/LSP and Analex to ½ Hz or 1 Hz required sample rate (see Weekly Status report dated 22 SEP 10) however 25 Hz was kept for feasibility purposes.

7. The system shall be capable of down linking entire stored contents within CubeSat to NASA Hanger AE on CCAFS within 24 hours following ejection from PPOD.

8. The system shall be capable of commanding on/off CubeSat power through other existing launch vehicle systems.

In order to generate a holistic list of requirements, these eight top-level requirements must be broken down into sub-level requirements. To do so, the requirements were organized in a way that allows them to be decomposed in an understandable manner. The first step is to determine the top-level Operational requirements. These can then be broken down into derived functional and organic requirements. The five Operational requirements can be seen below and Appendix A lists all of the derived functional and organic requirements that are associated with the completion of these eight top-level requirements.

1. The system shall comply with the Flight Mission and Design Requirements in the CubeSat to P-POD ICD.
2. The system shall comply with the Mechanical Requirements of the associated CubeSat mission.
3. The CubeSat shall be tested under specific conditions to ensure survivability during the integration process at Cal Poly, the transportation to the launch site and powered flight.
4. The CubeSat shall gather environmental data from three sensor sources.
5. The system shall be capable of gathering and storing data recorded by the sensors.
6. The system shall be capable of relaying stored data from the CubeSat.

It is important to note that all of the requirements listed above are subject to change – by NASA – after the conclusion of the Feasibility Study. Should certain requirements be found to be impossible, or of a high risk, then the project may change to account for these conditions.

Functional Analysis

The functional analysis includes the implementation of Use Cases, Functional Block Diagrams, Functional Flow Diagrams, System Block Diagrams and Process Flow Diagrams. Each tool is demonstrated below.

Use Case

Below is the Use Case (UC) for the systems described by the given requirements. Here the system's behavior is described with respect to how it responds to a request that originates from outside the system. The figure exemplifies what the system will do and "who" will tell the system to do it. The UC below is one for the top-most levels of the CubeSats functions.

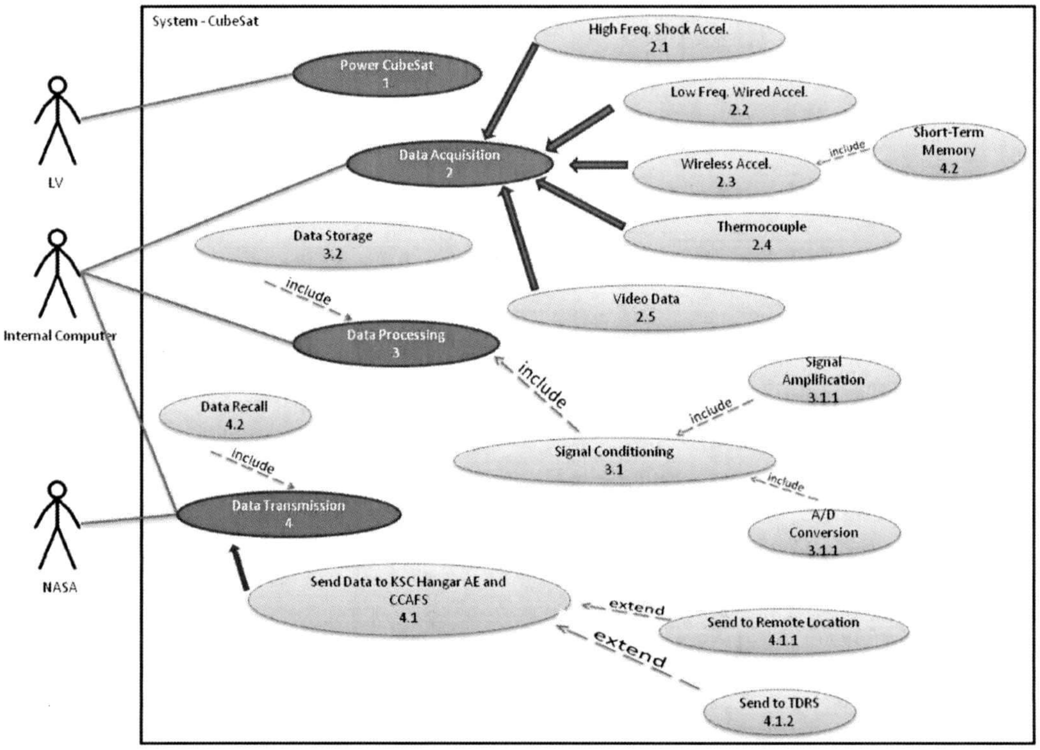


Figure 4: Top-Level Use Case

In this figure, the system is treated like a black box, and all system functions and responses are viewed from outside the system. The numbers in the figure just signify parent daughter relationships. The solid arrows signify direct requirements. For instance, gathering the various sensor data are direct requirements that relate to the data acquisition function. The “include” arrows are used for upper-level derived requirements, such as the need for signal conditioning during the data processing function. Finally, the “extend” arrows show various actions that could be taken depending on the final layout of the system.

Functional Block Diagram

The Functional Block Diagram shows the CubeSat broken into its many different functions. Each function is referenced to the associated requirements listed in Appendix A. Not all requirements are addressed in the FBD. Since this diagram focuses on the functional aspects of the system, operational and organic requirements are not considered. For inclusion of all requirements, the Detailed Systems Block Diagram is used.

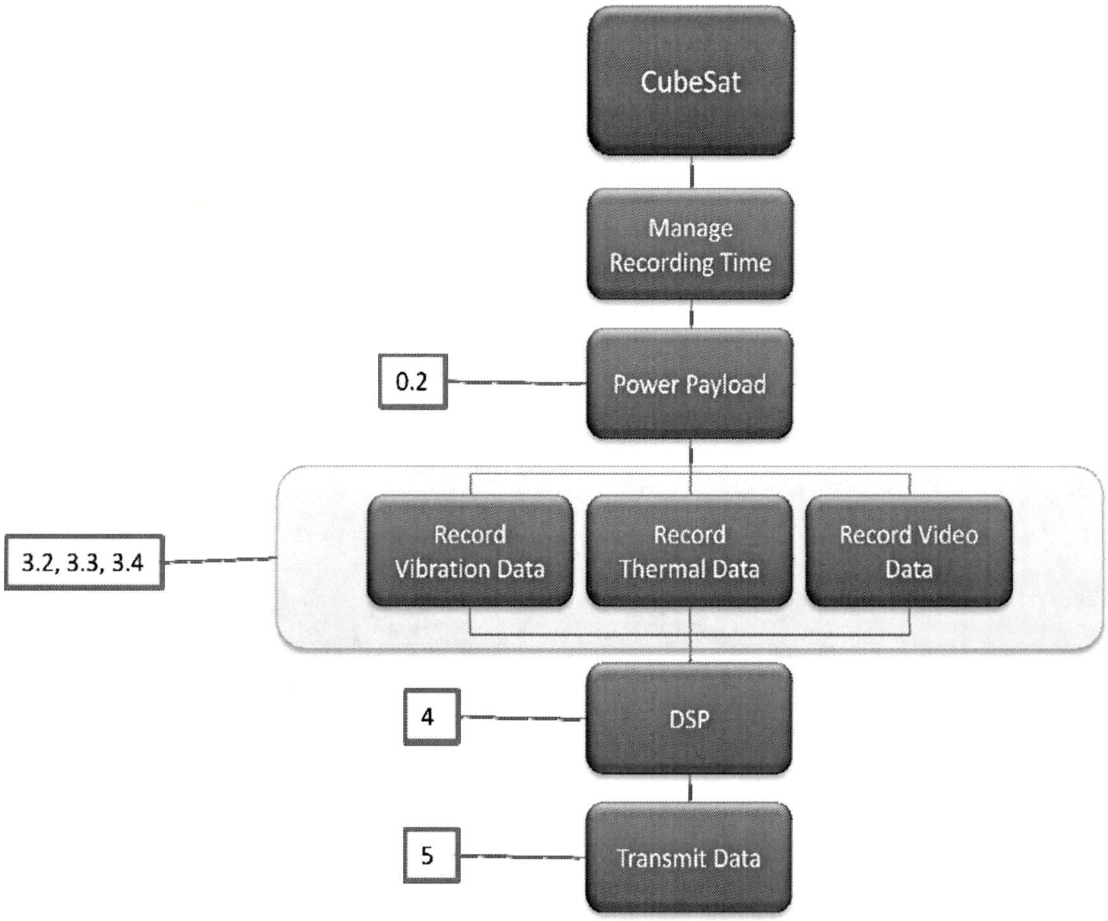


Figure 5: Top-Level Functional Block Diagram

The block diagram along with the references allow for the team to analyze the system as a whole and determine when each requirement has been met. Each function can be broken down into sub-functions that would relate to a different sub-requirement in the table in Appendix A.

Functional Flow Diagram

Below is a conceptual model of the major components of the system necessary to fulfill the requirements issued. This functional flow diagram (FFD) illustrates the required experimental functions that are to be accomplished.

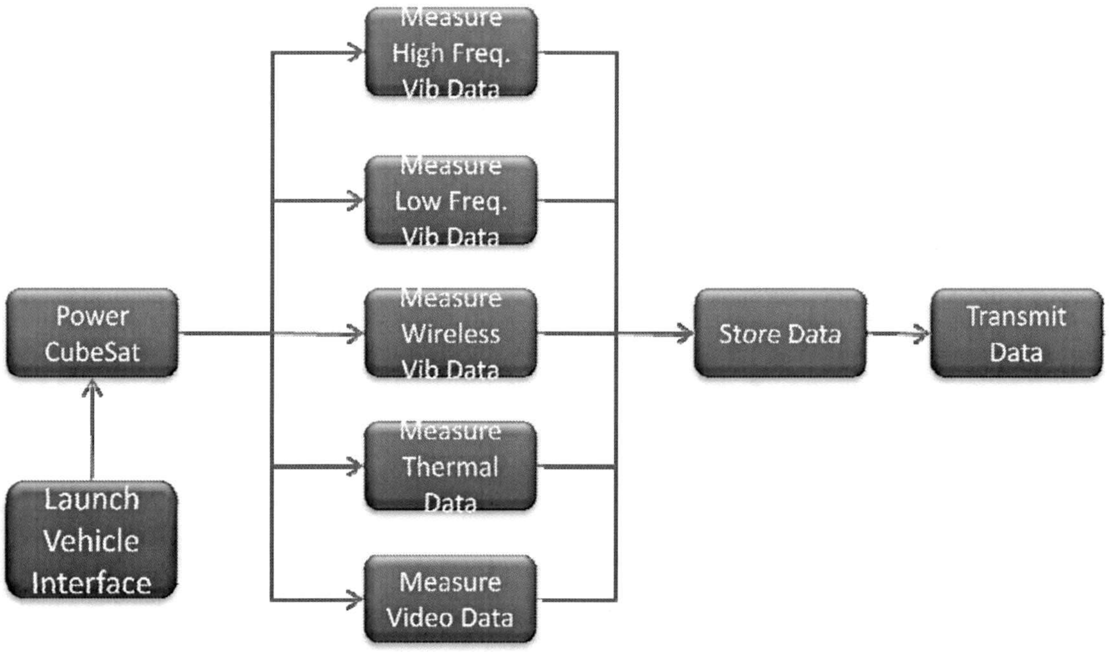


Figure 6: Functional Flow Diagram

The Diagram above shows the order of execution for each function that will be carried out during the planned experiment. The “Launch Vehicle Interface” block denotes the beginning of the experiment at T-5 seconds prior to launch. If available, the result of this function will be supplying power to the CubeSat sensors. Once power is applied to the sensors, they will measure each parameter mentioned in the requirements. The data will then be stored and transmitted to Hanger AE at the Kennedy Space Center.

Detailed Functional Flow Diagram

After generating a detailed FBD is was possible to create a more detailed FFD. Figure 7 demonstrates a more detailed approach to how the CubeSat system will function. Starting with a stakeholder requirement, the launch vehicle must have the means to turn the CubeSat on and off. The batteries will power the Electrical Power System (EPS) and distribute power to the accelerometers, thermocouple, and camera to measure vibration, thermal, and video data.

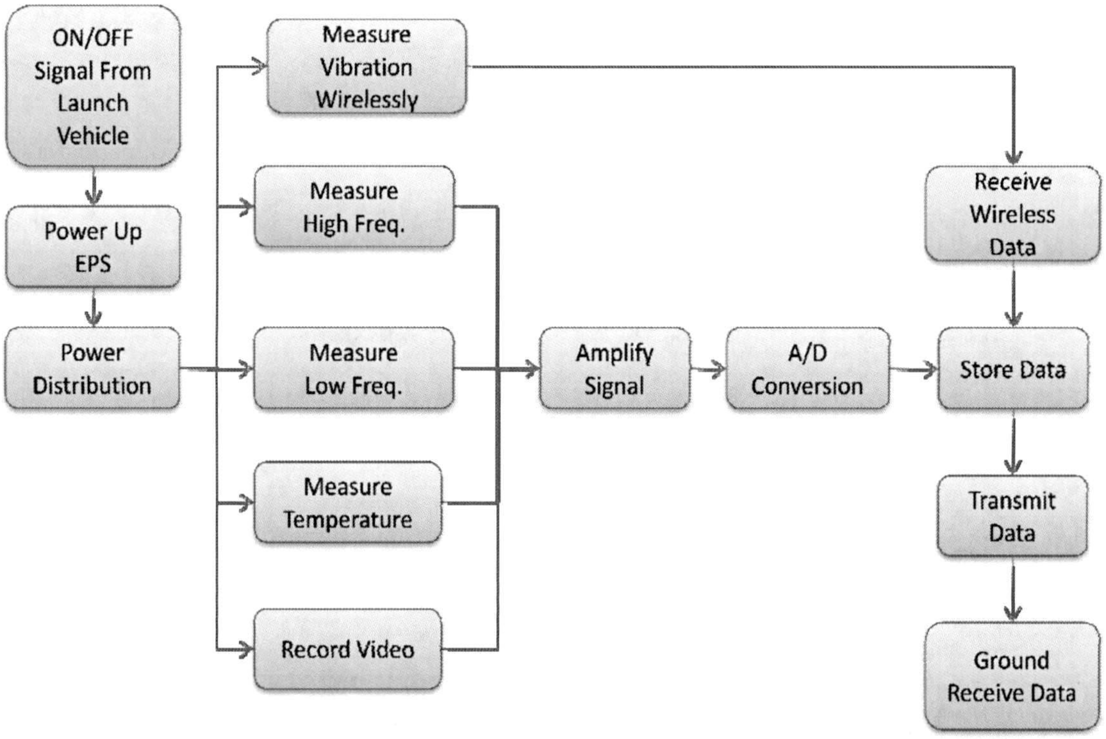


Figure 7: Detailed Functional Flow Diagram

Once the data is conditioned and converted it is stored until transmission during Low Earth Orbit (LEO). Since the purpose of the study is to conduct the feasibility of the experiment, it is important to generate a list of Commercial Off-The-Shelf (COTS) items that meet all of the requirements, Appendix B. Here it should be noted that many wireless accelerometers contained internal amplifiers, A/D converters, and antennas. That is why in Figure 5, “Measure Wireless Vibration” bypass’s the Amplify Signal and A/D Conversion blocks. It should also be noted, that if an ON/OFF signal is not available from the Launch Vehicle itself, a relatively simple “wake-up” circuit is necessary inside the CubeSat itself to power up appropriate sensors and data storage to capture engine start.

Detailed Systems Block Diagram

The detailed Systems Block Diagram seen below demonstrates what systems are required for the unit to perform as desired. While the functional diagrams explain what the CubeSat needs to do, the systems diagram explains how the CubeSat will complete the functions. Each system is positioned and labeled to show how the CubeSat systems connect with one another. As discussed earlier, this detailed diagram expounds the requirements to include sub-level requirements.

The requirements are broken down further than in the previous diagram and spread across the systems. In some instances where the requirements cannot be represented adequately, the requirements are included in the system one level above. For instance, both the camera and thermocouple requirements cannot be directly in touch with the corresponding blocks; therefore these requirements are included in the system block above (in this case the Internal Transmission System block). Again, all requirement numbers correspond to those representing the requirements in Appendix A.

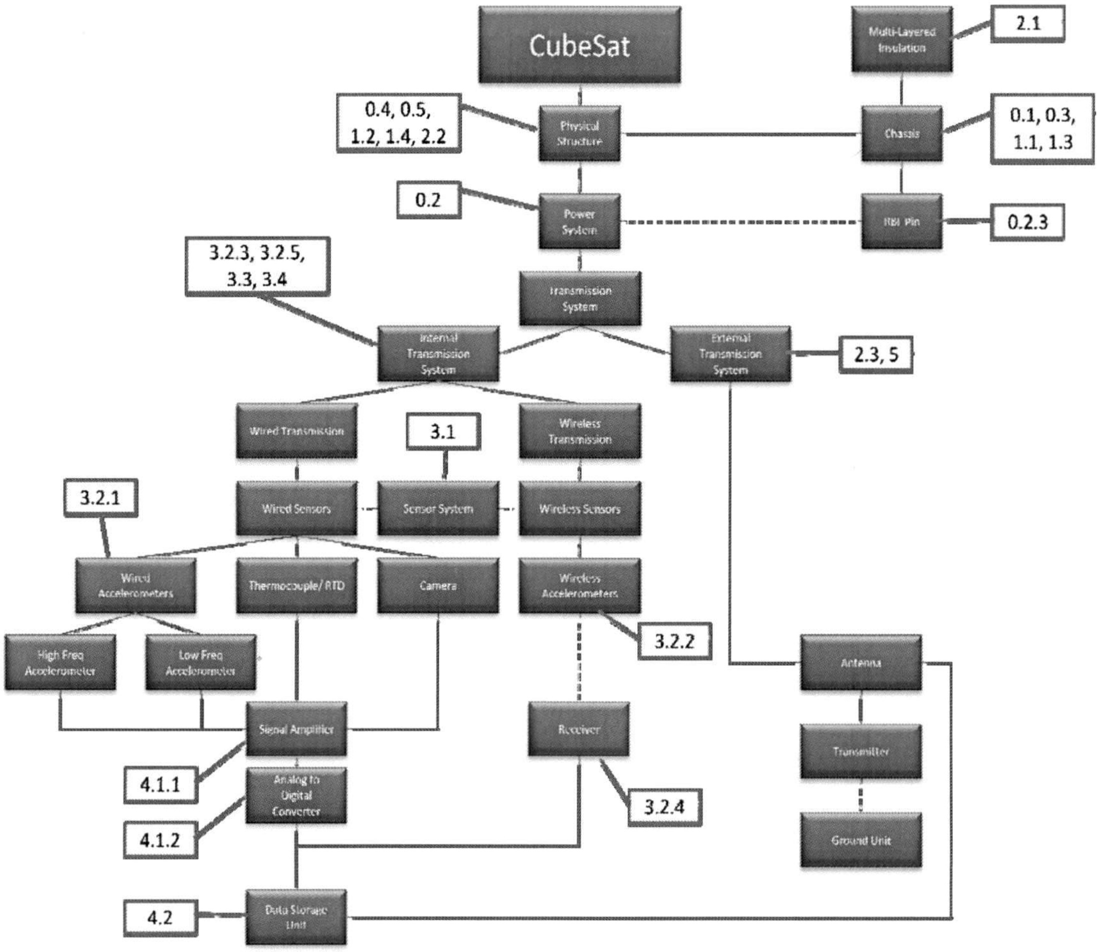


Figure 8: Detailed Systems Block Diagram

The initial Functional Block Diagram was broken down into greater detail. In order to integrate all functions, there exists a derived need for signal conditioning and analog to digital data conversion. The data signals, potentially all unique, are being transferred to a single data storage source. This means both signal amplitude and frequency must be unified to a compatible format for the data storage. In addition, since analog data cannot be stored, it must be converted into digital data.

The temperature of the operational environment within the CubeSat exceeds the limits of even some space qualified hardware. For this reason, it is necessary to use thermal blankets to insulate the hardware onboard from extreme heat and cold. This should provide an "in-CubeSat" environment that meets product specifications. Previous CubeSat missions openly documented – via internet websites and other publications – have used multi-layered insulation to provide an acceptable temperature range within the CubeSat environment. In addition to a mass limit of 2U (2 kg), it was identified that the system must also fit within 2U dimensions (10x10x20 cm). For a full list of stakeholder requirements, as well as derived requirements, please see reference A.

Process Flow Diagram

Once all of the systems have been identified, determining the order of processes is essential to the functional analysis. The Process Flow Diagram (PFD) takes the systems and breaks down the processes involved into a flow chart that can be organized by time.

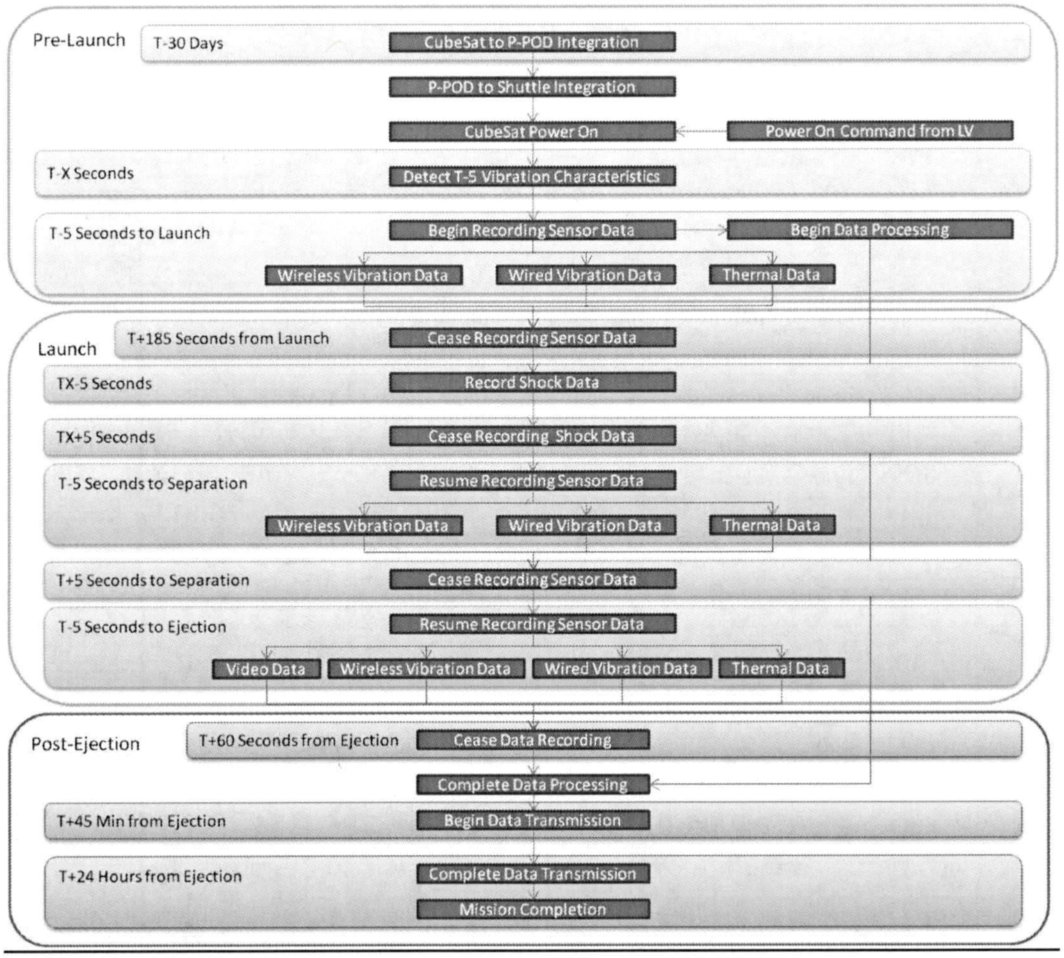


Figure 9: Process Flow Diagram

The PFD above breaks down all of the processes to be completed during the mission with respect to time. The experiment is broken down into three time frames, Pre-Launch, Launch, and Post-Ejection. The Pre-launch phase starts at the integration into the Cal Poly P-POD. The Launch sequence begins at T-0 seconds and the Post-Ejection phase begins at T-0 to ejection. The processes seen above include integration, time management, data collection, data processing and transmission. A more detailed breakdown is shown in the

Risk

Managing risk on a program typically involves establishing an assessment of the risks early on, defining a mitigation/management plan for each risk, and then monitoring the mitigation plan as the program is executed. A typical program plan for risk management is presented in Figure 9 below. The plan is broken up into several sections as defined below:

- Planning- The program leadership establishes the roles and responsibilities of those members who will be responsible for risk management during the program lifecycle. This typically includes the Chief Systems Engineer (CSE) in the leadership role, Quality Engineering, the individual IPT leaders from the various program segments and any Systems Engineers that exist on the program to provide technical leadership and expertise. An overall risk plan is established by the program leadership that reflects the risk posture accepted by management.

- Identification- The Risk Management Team then evaluates the proposed design solution and the system requirements to identify the significant risks as well as the program Technical Performance Metrics (TPM's). The identified risks are then categorized by their impact to Cost, Schedule or Technical performance.

- Analysis - Each identified risk is then evaluated to establish is probability of occurrence and the consequence of the occurrence. Next, the risk exposure is computed. This is a measure of how significant each risk is believed to be. From the risk exposure data, a risk map can be drawn which provides a graphical means of communicating the overall risk situation within the program.

- Mitigation - Each identified risk must have an associated mitigation plan. Depending on the level of risk exposure computed, each risk can be either monitored, or a detailed "Burn-down" plan is developed. Significant risks are typically linked directly into the integrated master schedule on the program to ensure visibility and proactive management of the risk item.

- Monitoring- As the program is executed, the individual risk items are closely monitored by the Risk Management Team. The computed risk exposure for each risk item may need to be updated as the design matures. Similarly, new risk items may warrant characterization and tracking.

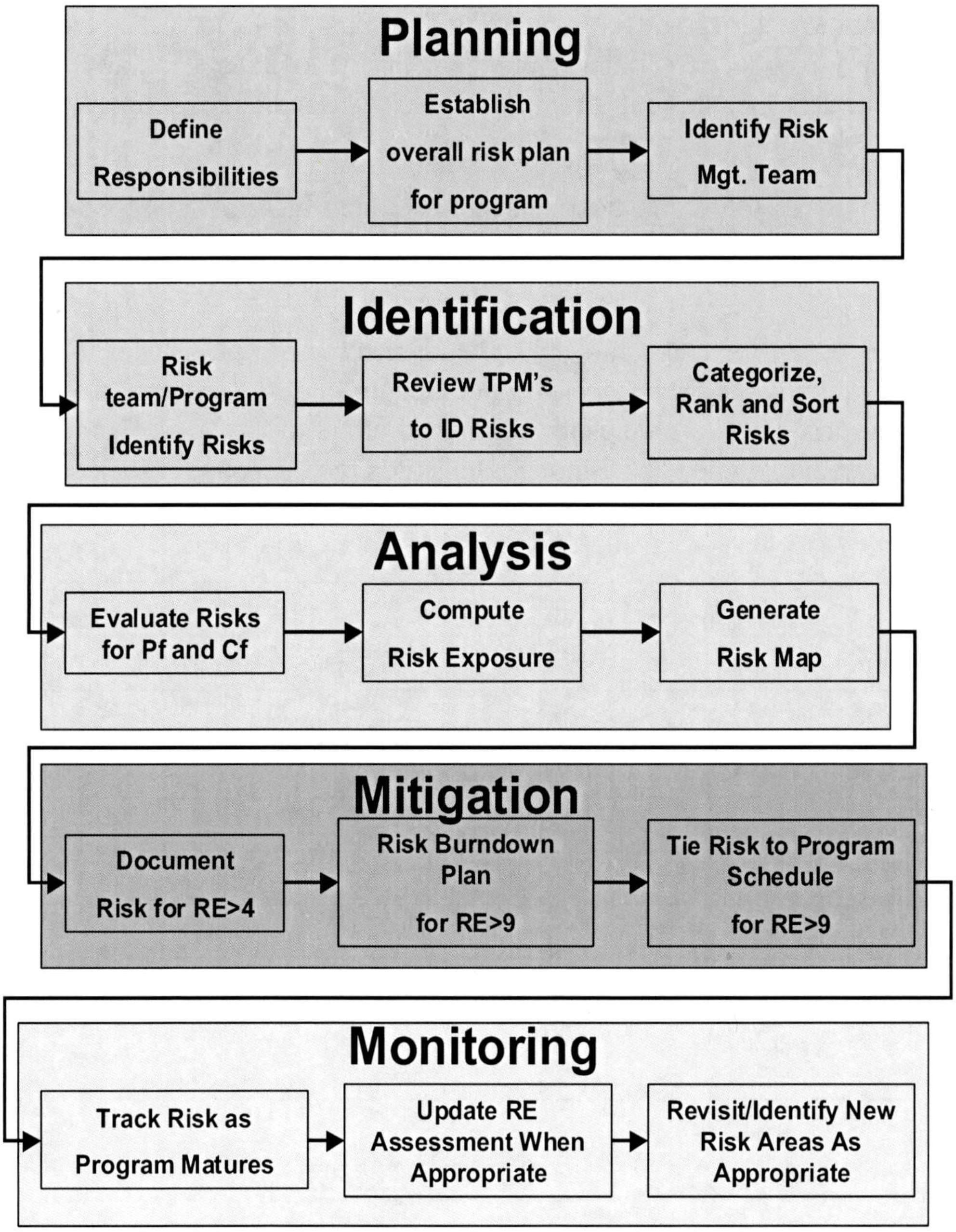


Figure 10: Risk Process Flow Diagram

In this particular instance, the interest is not yet in program execution, but rather in the feasibility of the proposed system requirements. In that context, the key system requirements are shown below as they fit into the risk plan. Additionally, since this is a feasibility analysis only, each of the risk items are evaluated only as they relate to technical performance. A requirement with low risk is one that is easy to achieve with the given resources. A requirement with medium risk would be one that is achievable with difficulties that must be mitigated. Finally, a high risk requirement is one that is severely difficult to satisfy for any number of reasons which include but are not limited to: technical, economical, and/or political.

The attributes of cost and schedule performance are not addressed here, but would be evaluated as a normal part of the preliminary design and proposal process.

The table below indicates the risk evaluation of the feasibility of the provided system requirements. The "Likelihood of Occurrence" (L) and the "Consequence of Occurrence" (C) are multiplied together to arrive at the "Risk Exposure" (RE). The color coding of the Risk Exposure indicates the assessed significance of the

Table 1: Risk Assessment Chart

		Performance				
ID	**Risk Area (Requirement)**	**L**	**C**	**RE**	**Notes**	**Mitigation**
RA-1	Design conforms to P-POD ICD	1	3	3	Notional layout validates the feasibility of this requirement.	None.
RA-2	System shall fit in 2U size and weight	3	4	12	No physical model made of CubeSat configuration.	Develop physical layout early in next phase of mission.
RA-3	3-axis wireless accel. At 4 kHz	3	3	9	Detailed EMI studies not done and out of scope of current effort.	Conduct early experiments during next phase of mission.
RA-4	3-axis wired accel. At 4 kHz and 20 kHz	2	3	6	Notional layout validates the feasibility of this requirement.	None.
RA-5	Video capture and store functionality	2	3	6	Notional layout validates the feasibility of this requirement.	None.
RA-6	Wired thermocouple at 25 Hz	1	3	3	Notional layout validates this requirement.	None.
RA-7	Downlink data within 24 hours	2	4	8	Data link models validates the feasibility of this requirement.	None.
RA-8	Electrical Power on/off control via launch systems	2	5	10	Availability of this interface is undecided.	Alternative method explored and feasible. Make determination of availability early in next phase of mission.

Risk Level	**RE**
Low	1 – 3
Medium-low	4 – 8
Medium-high	9 – 15
High	16 – 25

individual risk areas. The current system concept includes no "High" risk areas. All requirements are deemed feasibly with only medium-high level risk.

Table 2: Risk Area Prioritization based on Risk Exposure

ID	Risk Area (Title)	L	C	RE	Type
RA-2	System shall fit 2U size and weight	3	4	12	Technical
RA-8	Electrical Power on/off control via launch systems	2	5	10	Technical
RA-3	3-axis Wireless Accel. At 4kHz	3	3	9	Technical
RA-7	Downlink data within 24 hours	2	4	8	Technical
RA-4	3-axis Wired Accel. At 4kHz and 20 kHz	2	3	6	Technical
RA-5	Video capture and store functionality	2	3	6	Technical
RA-1	Design conforms to P-POD ICD	1	3	3	Technical
RA-6	Wired thermocouple at 25 kHz	1	3	3	Technical

By ranking the individual risk areas using the computed risk exposure one can easily see which requirements have the highest perceived risk in terms of feasibility.

Finally, the overall risk map of the requirements feasibility is shown below.

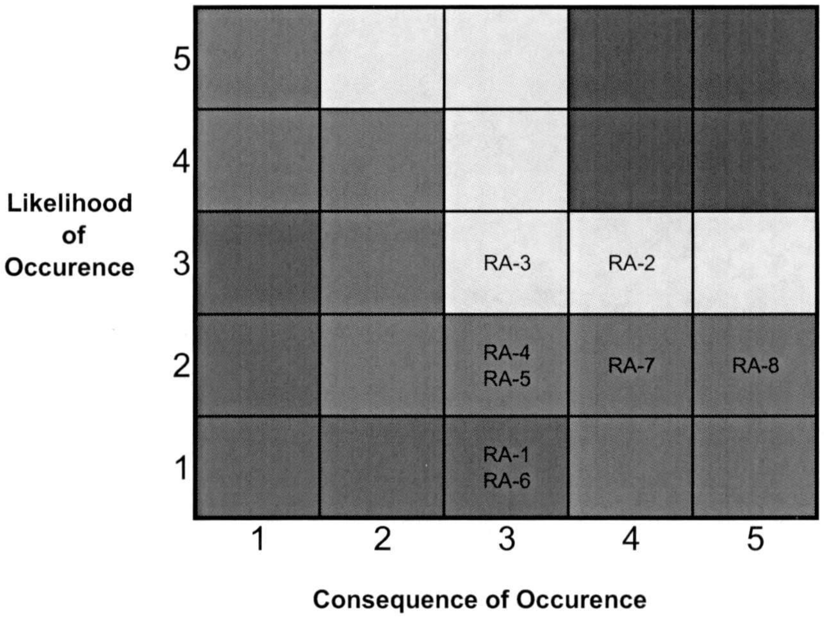


Figure 11: Overall Risk Map

Feasibility

To consider the feasibility of the system the team researched the availability of COTS items that satisfy the technical requirements. All components considered were either space qualified hardware or non-space qualified equivalent hardware that can stand up to the rigorous conditions during flight. A list of the researched items that meet the requirements are listed in Appendix B.

To consider the full feasibility of the CubeSat system, in addition to the eight requirements in the NASA SOW, we must consider derived requirements. Below is a list of system items related to the both the NASA/LSP requirements and the derived requirements.

Power System

The electrical systems feasibility is demonstrated in this section, according to a systems engineering methodology. The study will focus on points whose feasibility needs to be demonstrated, or risks need to be mitigated, whereas aspects that have already been shown as feasible through previous missions will be only quoted. Solutions will be proposed to achieve required functions, as well as a power analysis is presented. In this study, both the CubeSat system (CS2U) and its associate CubeSat (CS1U) are considered as one system of systems.

Electrical Systems Functions

According to the requirement analysis, electrical systems shall provide the following functions:

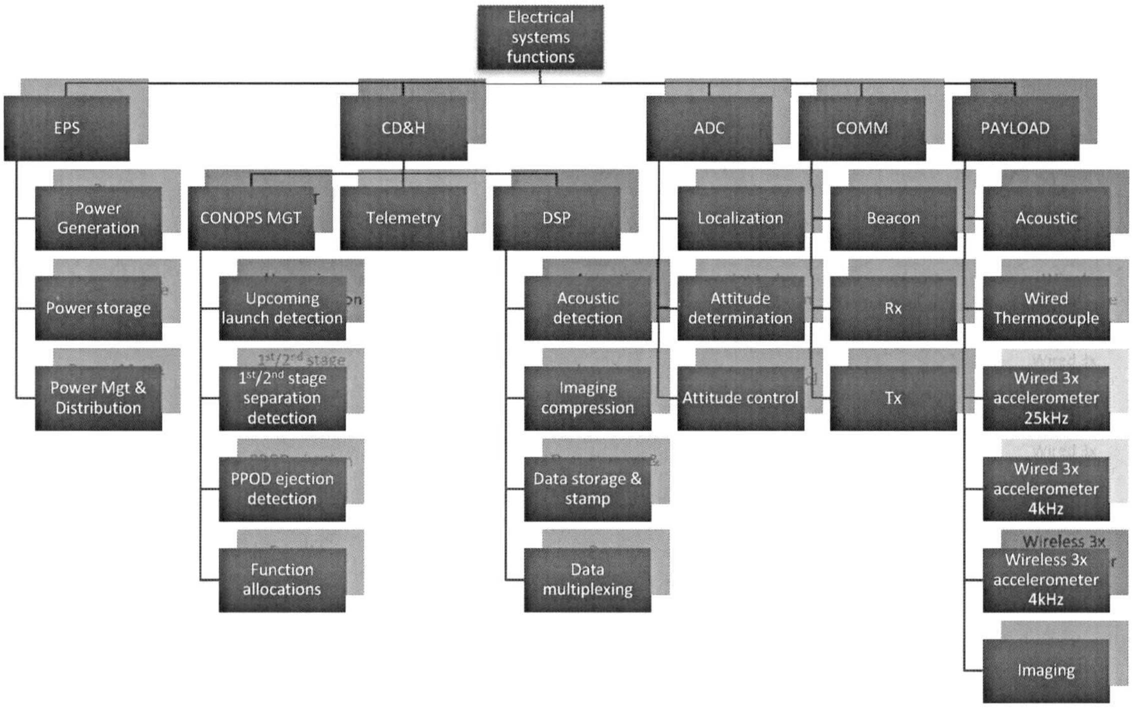


Figure 12: Electrical System Functions

Where the feasibility demonstration status is as follows

- Imaging: Feasibility demonstrated up to in a CubeSat mission.
- Wired 3x accelerometer: Feasibility demonstrated in a space mission (larger satellite)
- Wireless 3x accelerometer: Feasibility established in another industrial environment and/or
  in a laboratory

The following events serve as a reference to define the electrical systems dynamic behavior:

- T_0: Launch
- T_1: Booster separation and Second Stage Start
- T_2: Fairing Separation
- T_3: Third Stage Ignition
- T_4: Third Stage Shutdown
- T_5: Primary Payload Separation
- $T_{6:}$: CubeSat Ejection
- $P_{1,0}$ is the time lapse after the satellite ejection that corresponds to the beginning of the 1st communication pass. $P_{1,0}>45$ minutes.
- $P_{1,1}$ is the time lapse after the satellite ejection that corresponds to the end of the 1st communication pass. $P_{1,1}-P_{1,0} \approx 6$ min.
- $P_{2,0}$ is the time lapse after the satellite ejection that corresponds to the beginning of the 2nd communication pass. $P_{1,0}>45$ minutes.
- $P_{2,1}$ is the time lapse after the satellite ejection that corresponds to the end of the 2nd communication pass. $P_{2,1}-P_{2,0} \approx 6$ min.
- $P_{3,0}$ is the time lapse after the satellite ejection that corresponds to the beginning of the 2nd communication pass. $P_{1,0}>45$ minutes.
- $P_{3,1}$ is the time lapse after the satellite ejection that corresponds to the end of the 2nd communication pass. $P_{3,1}-P_{3,0} \approx 6$ min.

The dynamic behavior of the electrical systems can then be described as follows:

Figure 13: Power System Status

						Acquisition	
T_0 - 30 days	Sat. integration	Sleep	Sleep	OFF	OFF	Autonomous Acoustic or low power sensing	-
T_0 – Xs	Upon detection, CD&H initialization	ON	ON	OFF	OFF	OFF	-
T_0 – 5s	Start vibration, shock and thermal acquisition	ON	ON	OFF	OFF	Thermal (25Hz) Wired vibration (4kHz) Wireless vibration (4kHz) Wired Shock (25kHz)	-
T_0 + 5s	Stop shock acquisition	ON	ON	OFF	OFF	Thermal (25Hz) Wired vibration (4kHz) Wireless vibration (4kHz)	Wireless transmission for storage Data conditionning
T_0 + 180s	Start shock acquisition	ON	ON	OFF	OFF	Thermal (25Hz) Wired vibration (4kHz) Wireless vibration (4kHz) Wired Shock (25kHz)	Wireless transmission for storage Data conditionning
T_0 + 185s	Stop vibration, shock and thermal acquisition	ON	ON	OFF	OFF	OFF	Wireless transmission for storage Data conditionning
T_1	Start shock acquisition	ON	ON	OFF	OFF	Wired Shock (25kHz)	-
T_1 + 5s	Stop shock acquisition	ON	ON	OFF	OFF	OFF	-
T_2	Start shock acquisition	ON	ON	OFF	OFF	Wired Shock (25kHz)	-
T_2 + 10s	Stop shock acquisition	ON	ON	OFF	OFF	OFF	-
T_3	Start shock acquisition	ON	ON	OFF	OFF	Wired Shock (25kHz)	-
T_3 + 5s	Stop shock acquisition	ON	ON	OFF	OFF	OFF	-
T_4	Start shock acquisition	ON	ON	OFF	OFF	Wired Shock (25kHz)	-
T_4 + 5s	Stop shock acquisition	ON	ON	OFF	OFF	OFF	-
T_5	Start shock acquisition	ON	ON	OFF	OFF	Wired Shock (25kHz)	-
T_5 + 5s	Stop shock acquisition	ON	ON	OFF	OFF	OFF	-
T_6 – 5s	Start all sensors acquisition	ON	ON	ON	OFF	Thermal (25Hz) Wired vibration (4kHz) Wireless vibration (4kHz) Wired Shock (25kHz) Video	+ GPS ON
T_6 + 60s	Stop shock acquisition	ON	ON	ON	OFF	OFF	Wireless transmission for storage Data conditionning
$T_6 + P_{1,0}$	Beacon, Rx, then TX	ON	ON	ON	ON	OFF	-
$T_6 + P_{1,1}$	End of Pass 1 transmission	ON	ON	ON	Sleep	OFF	Battery charging
$T_6 + P_{2,0}$	Beacon, Rx, then TX	ON	ON	ON	ON	OFF	-
$T_6 + P_{2,1}$	End of Pass 2 transmission	ON	ON	ON	Sleep	OFF	Battery charging
$T_6 + P_{3,0}$	Beacon, Rx, then TX	ON	ON	ON	ON	OFF	-
$T_6 + P_{3,1}$	End of Pass 3 transmission & mission	ON	ON	ON	Sleep	OFF	CubeSat still operationnal for eventual additional missions

Finally, this type of mission requires the Cube Sat CD&H, EPS and Payload to be turned on during launch and ascent. Nevertheless, all external system radio wave emitting or receiving devices (GPS, Rx, Tx, beacon and solar panels) will be turned off during these two phases. This is a major difference compared to other usual CubeSat missions. The system shall consequently:

- Show that it cannot harm or interfere with any of the launch vehicle systems
    - This should be proven feasible with the understanding that the PPOD is acting as a Faraday cage, isolating sufficiently the 1mW emission of the wireless sensor from outside the PPOD, and,
    - With a risk assessment that concludes the system cannot self-combust during its operations in the launch vehicle. This should be feasible by using low power and space qualified/space flown parts or equivalents with appropriate testing during the subsequent design phase
- Receive the authorization to be powered and partially turned on during these 2 phases.

This is a key exception to usual requirements that is mandatory to fulfill the sensing and acquisition during launch requirements.

CD&H and Acquisition Feasibility, Architecture and Performance Options

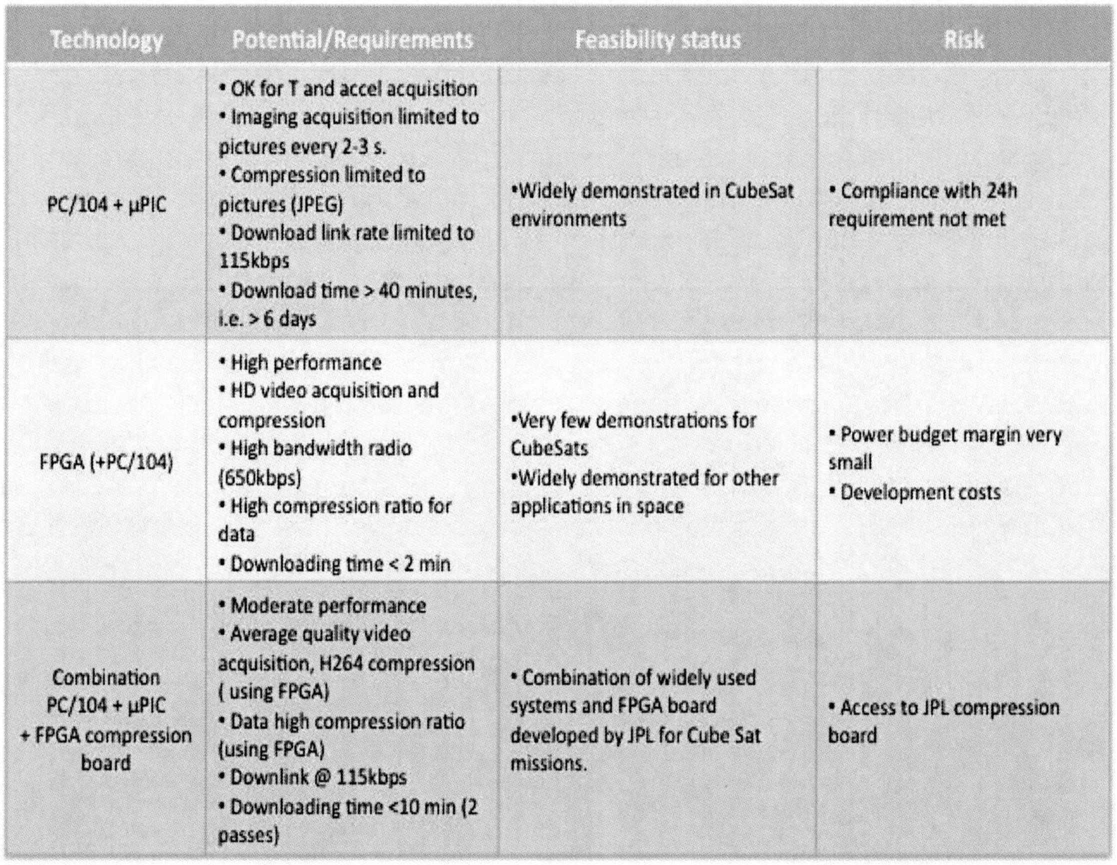
The electrical systems feasibility can be demonstrated by the implementation of two different architectures for the Command and Data Handling (CD&H) functions.

Both approaches use different technologies and offer different levels of performance. Thus, different compliance levels can be proposed. In parallel, development risks and eventually costs are similarly inversed.

These two approaches are

- the use of PC/104 motherboard associated to micro-controllers daughter boards for DSP and acquisition functions,
- or the combination of FPGA based boards, eventually associated to a PC/104 mother board.

The following table summarizes the main capabilities of the proposed technologies, as well as the feasibility status and risk evaluation



Technology	Potential/Requirements	Feasibility status	Risk
PC/104 + µPIC	• OK for T and accel acquisition • Imaging acquisition limited to pictures every 2-3 s. • Compression limited to pictures (JPEG) • Download link rate limited to 115kbps • Download time > 40 minutes, i.e. > 6 days	•Widely demonstrated in CubeSat environments	• Compliance with 24h requirement not met
FPGA (+PC/104)	• High performance • HD video acquisition and compression • High bandwidth radio (650kbps) • High compression ratio for data • Downloading time < 2 min	•Very few demonstrations for CubeSats •Widely demonstrated for other applications in space	• Power budget margin very small • Development costs
Combination PC/104 + µPIC + FPGA compression board	• Moderate performance • Average quality video acquisition, H264 compression (using FPGA) • Data high compression ratio (using FPGA) • Downlink @ 115kbps • Downloading time <10 min (2 passes)	• Combination of widely used systems and FPGA board developed by JPL for Cube Sat missions.	• Access to JPL compression board

Figure 14: Computer Technology Options

PC/104 and Microcontrollers based architecture

Several descriptions of microcontrollers are available on the literature. The following description is a definition given by the website Wikipedia: A **microcontroller** (sometimes abbreviated **µC**, **uC** or **MCU**) is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals Microcontrollers are designed for embedded applications. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes. The processor executes a single instruction per clock cycle, so its performance in IPS is equal to its clock speed. The processor has a number of modes of operation that balance power and processing requirements, all drawing 250µA per 1 MIPS. In this CubeSat the microcontroller has high performance of 32 bit, 40 I/O peripherals, Clock speed is 40MHz, interface is 2 SPI/I2C,1 USART, voltage supply is - 40 C to 85 C.

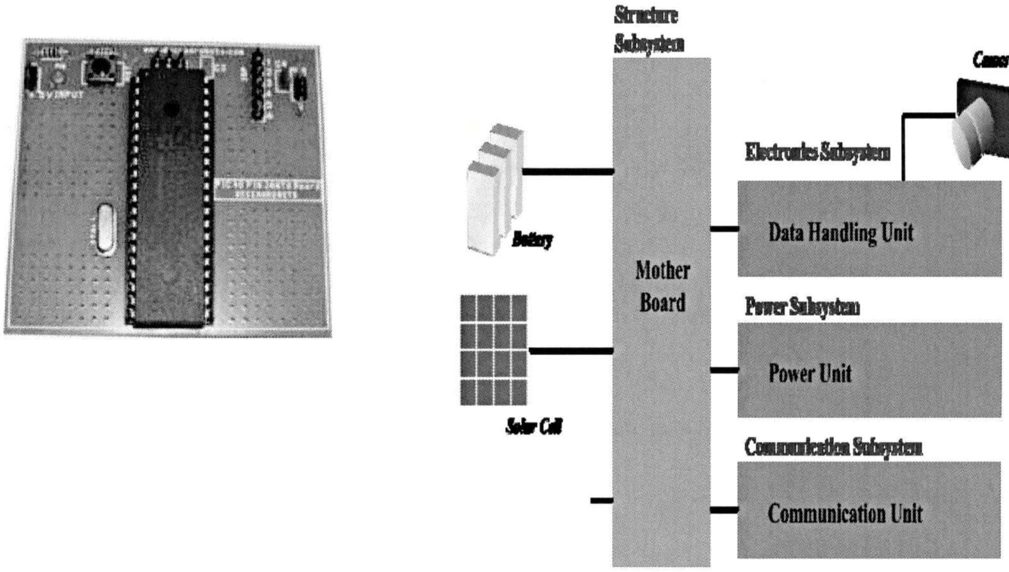


Figure 15: Microcontroller Architecture

Below is a partial notional layout of a microcontroller-based system to achieve the Command and Data Handling functions. All functions shall then be programmed within the Microcontroller unit.

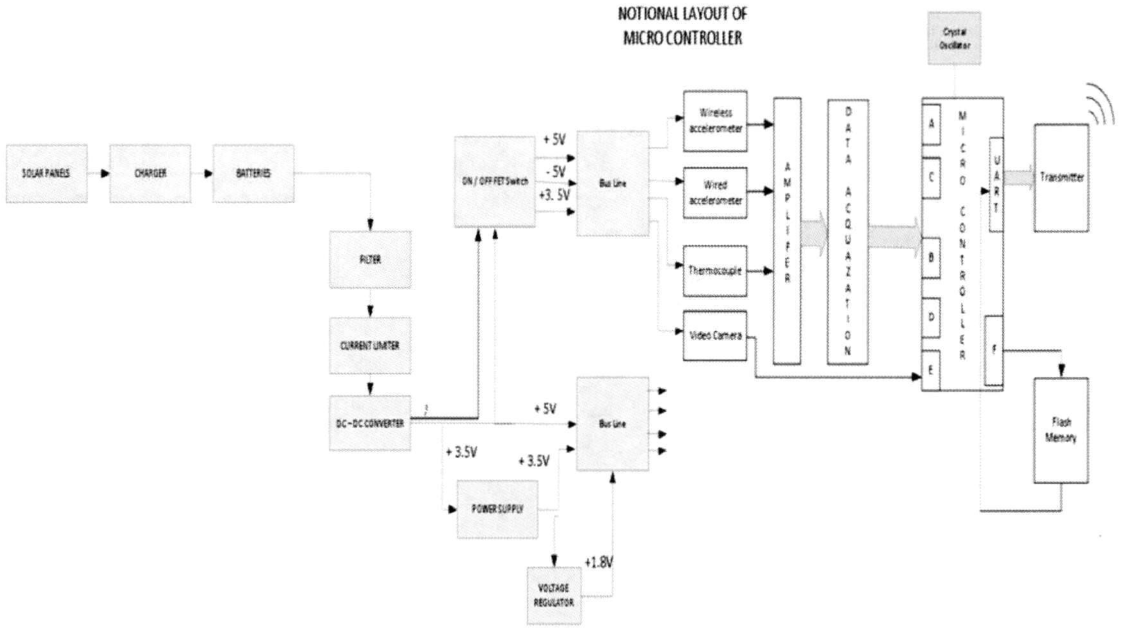


Figure 16: Microcontroller Notional Layout

The feasibility is established in terms of functional capabilities, mass, size and power, based on existing and widely used CubeSats sub-systems (c.f. annex for specifications):

- PC/104 CubeSat Kit□ Motherboard (MB) Hardware Revision: D
- Pluggable Processor Module CubeSat Kit□ D2 (PPM D2), as a high bandwidth (500ksps) acquisition card

FPGA based architecture

Several descriptions of microcontrollers are available on the literature. The following description is a definition given by the website Wikipedia: A **field-programmable gate array** (**FPGA**) is an integrated circuit designed to be configured by the customer or designer after manufacturing—hence "field-programmable" FPGAs contain programmable logic components called "logic blocks", and a hierarchy of reconfigurable interconnects that allow the blocks to be "wired together"—somewhat like a one-chip programmable breadboard. Logic blocks can be configured to perform complex combinational functions, or merely simple logic gates like AND and XOR. A few "mixed signal FPGAs" have integrated peripheral ADCs and DACs and analog signal conditioning blocks allowing them to operate as a system-on-a-chip. The FPGA is low power consumption Flexible, Multi-Standard I/Os: 1.5 V, 1.8 V, 2.5 V, 3.3 V Mixed Voltage Operation. Up to 840 I/Os with SEU-Protected Input, Output, and Enable Registers

- Up to 540 kbits Embedded SRAM
- Manufactured on 0.15 µm"

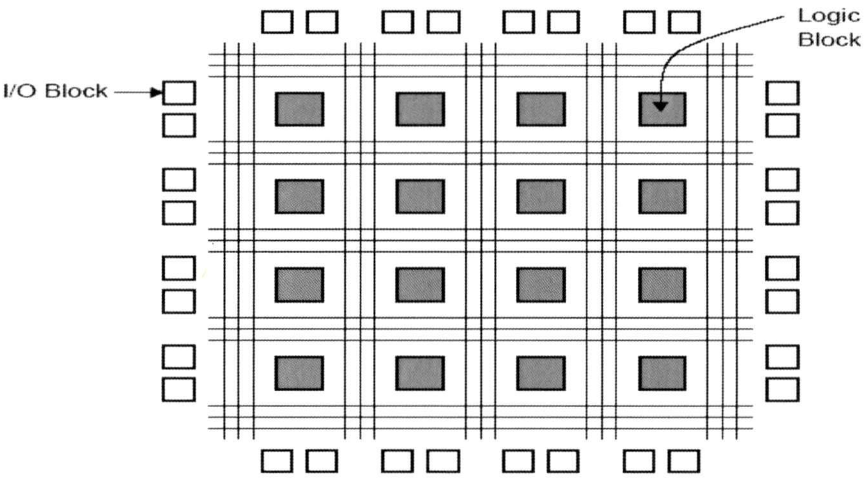


Figure 17: FPGA Architecture

Below is a partial notional layout of FPGA based architecture:

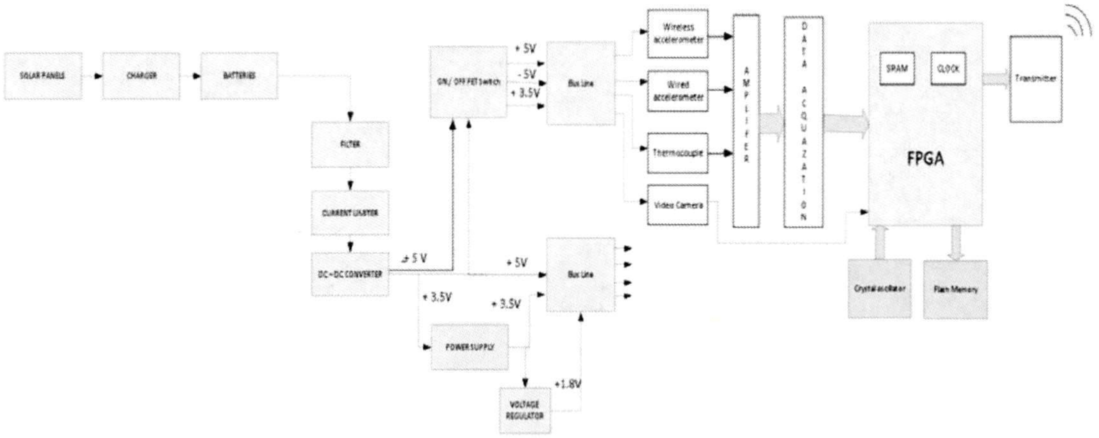


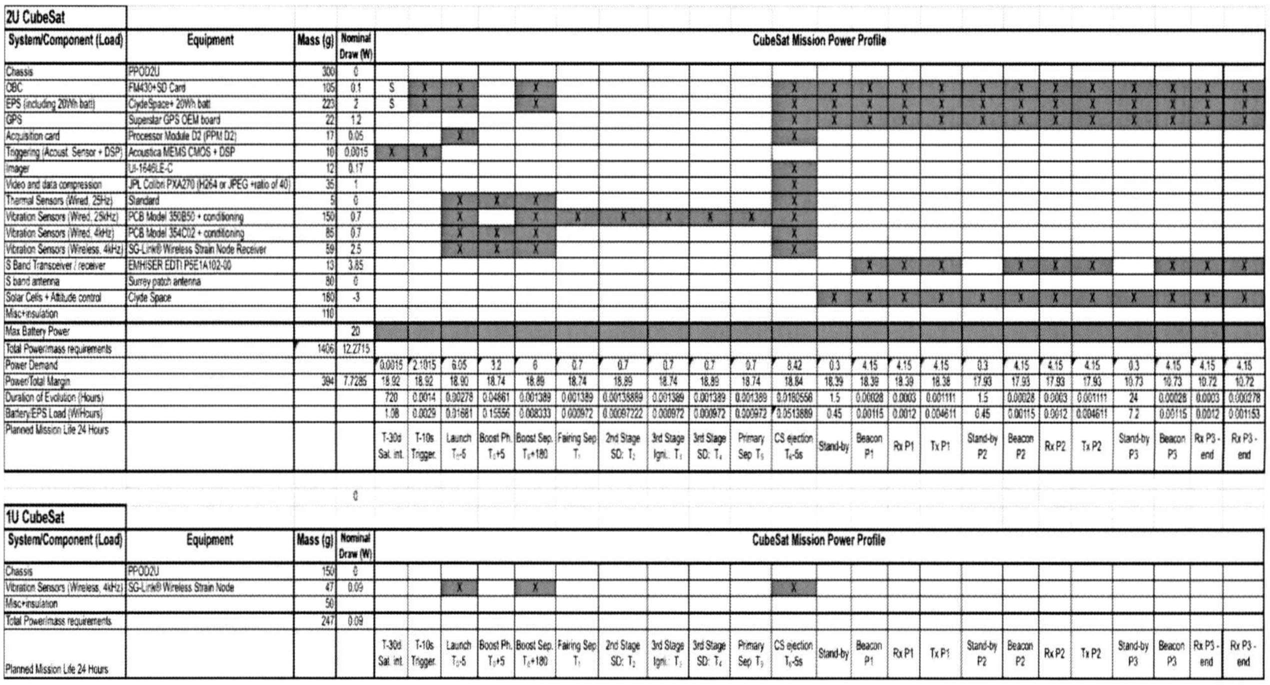
Figure 18: FPGA Notional Layout

The feasibility is established in terms of functional capabilities, mass, size and power, based on few existing FPGA based CubeSats sub-systems, as well as many larger satellite sub-systems (c.f. annex for specifications):

- COSMIAC CubeSat Reconfigurable Board (CCRB)
- JPL Xilinx Virtex V based board for cube-sat missions (M-Cubed)
- Berkley CINEMA Cubesat (using Xilinx Virtex V)
- Lockheed Martin Rabbit Cubesat (Xilinx Virtex V)

The power budget is strictly associated with the chosen system. However, in order to establish the feasibility, a power budget has been defined with a given set of potential equipment.

Table 3: Global Power and Weight Budget



2U CubeSat

System/Component (Load)	Equipment	Mass (g)	Nominal Draw (W)	CubeSat Mission Power Profile																						
Chassis	PPOD2U	300	0																							
OBC	FM430+SD Card	105	0.1	S	X	X		X						X	X	X	X	X	X	X	X	X	X	X	X	X
EPS (including 20Wh batt)	ClydeSpace+ 20Wh batt	223	2	S	X	X		X						X	X	X	X	X	X	X	X	X	X	X	X	X
GPS	Superstar GPS OEM board	22	1.2											X	X	X	X	X	X	X	X	X	X	X	X	X
Acquisition card	Processor Module D2 (PPM D2)	17	0.05			X								X												
Triggering (Acoust. Sensor + DSP)	Acoustica MEMS CMOS + DSP	10	0.0015	X	X																					
Imager	UI-1646LE-C	12	0.17											X												
Video and data compression	JPL Colibri PXA270 (H264 or JPEG +ratio of 40)	35	1											X												
Thermal Sensors (Wired, 25Hz)	Standard	5	0			X	X	X						X												
Vibration Sensors (Wired, 25kHz)	PCB Model 350B50 + conditioning	150	0.7			X		X	X	X	X	X	X	X												
Vibration Sensors (Wired, 4kHz)	PCB Model 354C02 + conditioning	85	0.7			X	X	X						X												
Vibration Sensors (Wireless, 4kHz)	SG-Link® Wireless Strain Node Receiver	59	2.5			X	X	X						X												
S Band Transceiver / receiver	EMHISER EDTI P5E1A102-00	13	3.85													X	X	X		X	X	X		X	X	X
S band antenna	Surrey patch antenna	80	0																							
Solar Cells + Attitude control	Clyde Space	180	-3												X	X	X	X	X	X	X	X	X	X	X	X
Misc+insulation		110																								
Max Battery Power			20																							
Total Power/mass requirements		1406	12.2715																							
Power Demand				0.0015	2.1015	6.05	3.2	6	0.7	0.7	0.7	0.7	0.7	8.42	0.3	4.15	4.15	4.15	0.3	4.15	4.15	4.15	0.3	4.15	4.15	4.15
Power/Total Margin		394	7.7285	18.92	18.92	18.90	18.74	18.89	18.74	18.89	18.74	18.89	18.74	18.84	18.39	18.39	18.39	18.38	17.93	17.93	17.93	17.93	10.73	10.73	10.72	10.72
Duration of Evolution (Hours)				720	0.0014	0.00278	0.04861	0.001389	0.001389	0.00138889	0.001389	0.001389	0.001389	0.0180556	1.5	0.00028	0.0003	0.001111	1.5	0.00028	0.0003	0.001111	24	0.00028	0.0003	0.000278
Battery/EPS Load (W/Hours)				1.08	0.0029	0.01681	0.15556	0.008333	0.000972	0.00097222	0.000972	0.000972	0.000972	0.0513889	0.45	0.00115	0.0012	0.004611	0.45	0.00115	0.0012	0.004611	7.2	0.00115	0.0012	0.001153
Planned Mission Life 24 Hours				T-30d Sat. int.	T-10s Trigger.	Launch T_0-5	Boost Ph. T_0+5	Boost Sep. T_0+180	Fairing Sep T_1	2nd Stage SD: T_2	3rd Stage Igni.: T_3	3rd Stage SD: T_4	Primary Sep T_5	CS ejection T_6-5s	Stand-by	Beacon P1	Rx P1	Tx P1	Stand-by P2	Beacon P2	Rx P2	Tx P2	Stand-by P3	Beacon P3	Rx P3 - end	Rx P3 - end

0

1U CubeSat

System/Component (Load)	Equipment	Mass (g)	Nominal Draw (W)	CubeSat Mission Power Profile																						
Chassis	PPOD2U	150	0																							
Vibration Sensors (Wireless, 4kHz)	SG-Link® Wireless Strain Node	47	0.09			X		X						X												
Misc+insulation		50																								
Total Power/mass requirements		247	0.09																							
Planned Mission Life 24 Hours				T-30d Sat. int.	T-10s Trigger.	Launch T_0-5	Boost Ph. T_0+5	Boost Sep. T_0+180	Fairing Sep T_1	2nd Stage SD: T_2	3rd Stage Igni.: T_3	3rd Stage SD: T_4	Primary Sep T_5	CS ejection T_6-5s	Stand-by	Beacon P1	Rx P1	Tx P1	Stand-by P2	Beacon P2	Rx P2	Tx P2	Stand-by P3	Beacon P3	Rx P3 - end	Rx P3 - end

The global view of the power budget, that also includes the mass budget, is shown in Table 3. For the 2U and 1U CubeSats, Table 3 shows weight and power budgets, as well as the power status of the CubeSat sensors related to key CubeSat mission events. The green fields with an "X" indicate an "on" status for that particular device. Looking at the power and mass margins demonstrates the feasibility of the system from a power and mass point of view.

The functions to be achieved by the Electrical Power Systems are:

- To provide power generation
- To store power
- And to manage power distribution

Below is an example of a notional layout. All identified systems in this study either require 5V or 3.3V. These levels are quite common in CubeSat missions. Therefore we do assume the power level feasibility has already been demonstrated.

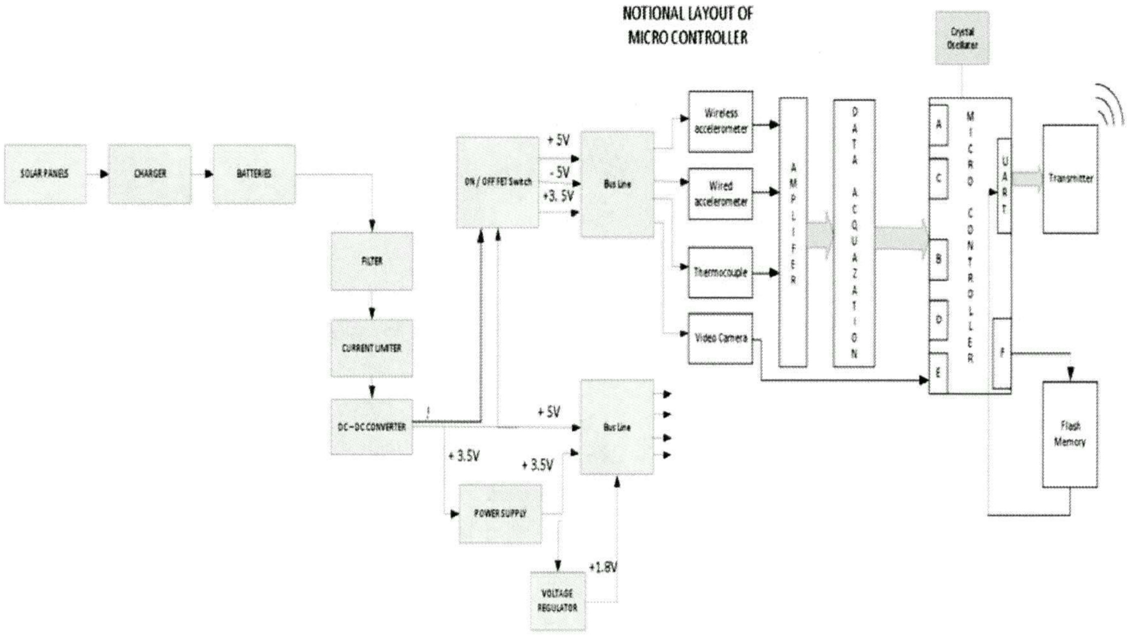


Figure 19: Accepted Notional Layout for Analysis

The previously mentioned power budget analysis shows we need to implement

- A 20Wh battery system, especially to enable the acoustic triggering detection during 30 to 60 days, and still having enough power to achieve the mission.
- An average 3W power production by solar panels, in order to enable a 3rd pass orbit to mitigate the risk of one pass without signal acquisition. It is also quite interesting to note that a 3W power production capability

will extend the satellite life time by 1 day longer. A production of 4W will then considerably extend the lifetime of the CubeSat, since the electrical power production will be sufficient to make the satellite autonomous.

A comprehensive solution that has already been extensively demonstrated during CubeSat missions can be used in this present system:

- Clyde-Space EPS 2U, with 20Wh batteries
- Clyde-Space 1 Side 2U solar panel that can provide up to 6W of power.

Electrical systems feasibility is established in compliance with these study requirements:

- Most functions have already been demonstrated in other CubeSat missions
- The functions of acceleration sensing and recording have already been demonstrated in larger satellite missions
- The wireless sensing technology has already been demonstrated in highly harsh environments, such as turbine monitoring in nuclear plants.
    - Its use will not suffer from interference in the PPOD system and the performance of 4Khz sampling has already been demonstrated.
    - Its use will not interfere during launch, as the transmitting sensor and receiver are located in the PPOD system that acts as a Faraday cage.
    - The use of such a transmission during ejection will require an additional authorization from NASA.
- The size, mass and power budget analysis for one chosen solution demonstrates that at least this solution as a system is feasible.

Electromagnetic Interference

The system concept presented in the feasibility study includes sensors and communication systems that necessarily transmit RF energy from within the CubeSat structure. This presents the possibility of EMI with other electronic devices located in close proximity to the CubeSat itself. This would potentially include the launch vehicle and any payload contained within/upon it.

The Cubesat technology baseline includes the use of a specialized launching device that ejects the CubeSat at the desired time and location. The Poly-Picosat Orbital Deployer is a metallic box that encapsulates up to 3 CubeSats during launch. For all practical purposes, this metallic “box” acts as a Faraday Cage limiting or even eliminating any radiated emissions that might otherwise escape and interfere with other systems. To validate this assertion and the affectivity of the Faraday Cage an experimental test would be required. This test is proposed for the development phase of the program.

In the system concept presented herein the CubeSat is active within the P-POD structure to facilitate collection of sensor data at key times of interest within the launch vehicle mission profile including: main engine ignition, booster separation and CubeSat ejection. To protect against stray radiated emissions from these systems within the CubeSat, a design implementing EMI shielding is recommended.

By incorporating EMI shielding within the system design and taking advantage of the natural shielding provided by the P-POD launcher, the risk of EMI related issues is reduced. The specific EMI performance characteristics would need to be quantified during a comprehensive test program early in the program lifecycle.

CubeSat Physical Structure

The available mass in a 2U CubeSat System is 2000g (4.409 lbs) having dimensions of 10cm x 10cm x 20cm. There are multiple commercially available CubeSat products through many different companies. For example, Pumpkin Incorporated offers COTS CubeSat structures weighing as little as 229 g. Refer to Appendix B for a list of COTS items used in this feasibility study. All weight estimates are included alongside the power estimates for the entire feasibility study and can be found in the Power and Mass Budget section of the report. For these estimates, a notional layout was considered in order to determine feasibility.

A derived requirement is that the system must fit in a 2U CubeSat structure, 10cm x 10cm x 20cm (2000 cm^3). The sum of the volumes of all components can lend to the feasibility of this requirement, but by itself means nothing. Devising a layout for all the components, while considering their volumes, can prove this requirement feasible, however, design is outside the scope of the NASA SOW.

The CubeSat structure, equipment (accelerometers, antennas, transmitters etc.) and potential vibration mitigation equipment must survive the vibration and shock environment. In this feasibility study, the criteria are presented based on previous CubeSat flights and on existing NASA documents.

Vibration Environment

Payloads (such as the Cube Sat) must survive stringent acoustic, shock, sine and random vibration requirements. The main documents governing the acceptance and workmanship testing are: NASA Standard Technical Document 7003, Pyroshock Test Criteria; NASA Standard Technical Document 7001, Payload Vibroacoustic Test Criteria; and NASA Standard Technical Document 7002, Payload Test Requirements.

The section presents very briefly some of the testing requirements outlined in the NASA documents [1,2, 3]; the tests performed for the future CubeSat will adhere strictly to the procedures outlined there.

A summary of the vibroacoustic testing is shown in the table below

Table 4: Vibroacoustic testing Summary

Maximum expected flight level (MEFL) 95%/50% Probability Level
Test levels
Prototype/protoflight qualification MEFL + 3 dB
Flight acceptance MEFL* - 3 dB
Minimum vibration workmanship test 6.8 grms
Minimum acoustic workmanship test 138 dB
Test durations
Prototype qualification, single mission 2 minutes
Prototype qualification, multiple (N) reflights 2 + 0.5N minutes
Protoflight qualification 1 minute
Flight acceptance 1 minute

*MEFL stands for minimum expected field level.

Shock Environment

The shock environment criteria are important for CubeSat structure and equipment survivability. The shock environment criteria may be inferred from NASA STD 7003[1].

The document [1] characterizes the shock environment as being categorized into far field, medium field or near field. It would be a safe assumption to consider that the shock environment around the CubeSat may be characterized as being "far field" if the source of the shock is the rocket firing, since the payload is placed on top of the rocket. The far-field environment is dominated by structural resonances, with peak accelerations below 1000 g and most of the spectral content below 10 kHz. NASA-STD-7003 also recommends several levels of shock testing. The preferred method would actually require the actual pyrotechnic device to be used. In lieu of that device, a shaker system may be used to simulate pyrotechnic shock- this method only works for shock levels characteristic of far-field. For medium and near field simulated testing, a different device may be used (drop-tester) to simulate shocks.

Swept Sine Testing

The payload must also pass a swept sine test, as established by NASA STD 7002, Payload Test Requirements [3]. The requirements are that sinusoidal sweep vibration (5 to 50 hertz [Hz]) for expendable launch vehicle (ELV) must be performed to qualify hardware for the low frequency (less than 50 Hz) sinusoidal transients or the sustained sinusoidal environments when they are present in flight. These tests will be conducted at levels that are 1.25 times the flight limit levels and at a sine-sweep rate of 4 octaves per minute.

Random Testing

Random testing for payloads is specified by NASA Standard Technical Standard 7001, Payload Vibroacoustic Test Criteria and NASA Standard Technical Standard 7002, Payload Test Requirements [2], [3]. The component will be subjected to the random vibration test along each of three orthogonal axes for the appropriate duration as specified in the table below.

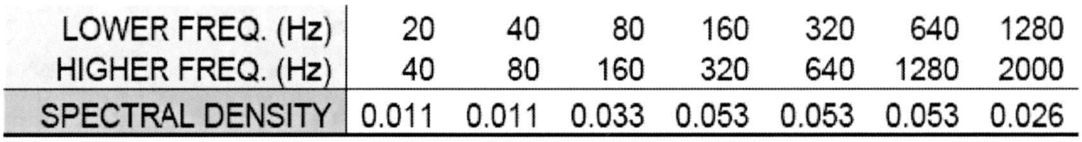
Table 5: Random testing Criteria

20 Hz @ 0.01 g2/Hz
20 to 80 Hz @ +3 dB/oct
80 to 500 Hz @ 0.04 g2/Hz
500 to 2000 Hz @ -3 dB/oct
2000 Hz @ 0.01 g2/Hz
Overall Level = 6.8 grms

Alternatively, if the launch vehicles changes to a DNEPR rocket, the random testing vibration profile changes as shown in the following figure [4].

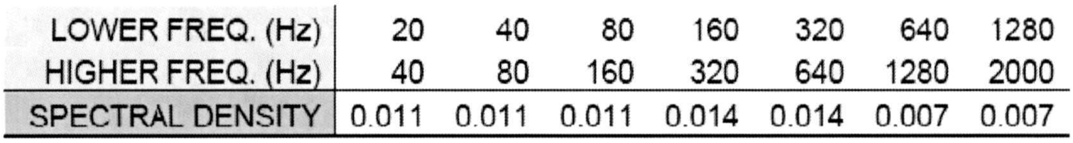
Table 6: Testing Characteristics for other Potential Launch Vehicles

DNEPR High Level Qualification Profile:



LOWER FREQ. (Hz)	20	40	80	160	320	640	1280
HIGHER FREQ. (Hz)	40	80	160	320	640	1280	2000
SPECTRAL DENSITY	0.011	0.011	0.033	0.053	0.053	0.053	0.026

DNEPR Low Level Qualification Profile:



LOWER FREQ. (Hz)	20	40	80	160	320	640	1280
HIGHER FREQ. (Hz)	40	80	160	320	640	1280	2000
SPECTRAL DENSITY	0.011	0.011	0.011	0.014	0.014	0.007	0.007

Previous Experience with CubeSat Vibration Testing at Florida Institute of Technology

The equipment present at the Florida Institute of Technology would allow testing of the CubeSat for vibration and shock criteria (suitable mostly for far-field only). A 1200-lbf Unholtz Dickie TA206 electromagnetic shaker system, complemented by a random vibration and a sine controller are the main pieces of equipment that would be used in the tests. The frequency range of the shaker extends up to approximately 3000 Hz and produces approximately 6 g peak acceleration at that frequency with a 1 kg mass.

FIT also possesses a Dynatup drop tester controlled via National Instruments software, which could simulate medium field shocks on the CubeSat (up to approximately 250 g's).

Previous experience with FUNSAT (a CubeSat-class satellite) developed by students at Florida Tech for an in-state competition, was very good. The students were able to perform shock, random and sine testing using the aforementioned equipment for qualification purposes. It is worth mentioning that he FIT FUNSAT won the first place in that competition.

CubeSat Operational Environment

The CubeSat will operate in Lower Earth Orbit. Here, temperatures can reach as low as 3 degrees Kelvin. It is believed that the use of space blankets, or Multi-Layered Insulation (MLI), can insulate the heat generated by the onboard components creating an "in-CubeSat" environment between 218.15 K and 423.15 K. These temperatures are within the operational range of the space qualified (or equivalent) hardware. However, the performance details of the MLI are TBD.

Launch environment

Launch environmental factors include launch vibrations and aero-acoustic loads. These are dependent upon the launch vehicle and structural design must take into account these factors. Values for these parameters can be found in the specific launch vehicle payload planner's guide.

Space environment

For orbits below 1000 km, the effects of atmospheric drag are significant. Drag acts to reduce velocity in the perigee of the orbit causing a lowering of apogee of the orbit. For a short, several day mission this should not be a major concern.

For this study, three orbital realms are considered, lowest Earth orbit, from 300 to 500 km, middle Earth orbit from 500 to 1000 km and high Earth orbit from 1000 km to 1500 km. Fortunately the CubeSat mission in question is very short (on the order of days) and most space environment effects are thusly lessened.

Atomic oxygen (AO) flux is a major concern for orbits from 300 to 900 km. AO is a vigorous oxidizer and requires the use of non-oxidizing external spacecraft surfaces.

Most materials will outgas in the vacuum environment of space. Metals usually have an outer layer into which gases have been absorbed on Earth. These gases are quickly released upon entering the space environment. Polymers and plastics may outgas severely. Material selection must take into account their outgassing potential since this outgassing can cause condensation on sensor surfaces (such as cameras). Bake out can also be used on materials that may be required for use but also may have outgassing concerns.

Lubricants can desiccate in space and so any hinges/booms or other deployable systems that use lubricants have to specify lubricants with outgassing properties as well as viscosity, vapor pressure, operating temperature ranges in mind.

With any on-board electronics that are active during ascent care must be taken to avoid electrical arcing. This equipment should be tested ahead of time in a thermal vacuum chamber.

A spacecraft in a relatively low Earth orbit such as described in this study can develop an absolute charge floating within a few negative volts of the surrounding plasma environment. If the spacecraft voltage bus operates at 40 volts or less then arcing should not be a problem.

Radiation environment

Radiation can affect electronics in primarily two ways:

1. Single Event Upsets - usually a bit flip (software) or a hardware anomaly (latchup) caused by a short burst of radiation (such as a solar flare). Latchups are much more dangerous.

2. Constant bombardment of radiation over time

Single event upsets are usually helped by using a Watch Dog timer on the CPU or by using a second CPU to watch the primary. Therefore all electronics should use watchdog timers or current monitoring/reset circuits to reset the system in the event of these radiation effects.

Constant bombardment is a function of location in space. It is most prevalent outside Earth's magnetosphere (GEO and beyond) and is much less of a problem in the relatively low Earth orbits for this mission. Also for a mission duration of days total radiation dose is not a factor. Most COTS electronics components can withstand 3KRad total radiation dose. At an orbital altitude of 1500 km the required aluminum thickness, assuming a hemispherical shield, would be 0.043 inches (0.11 cm) for a year-long mission. Lower altitude missions would experience less radiation total dosage.

Thermal environment

The spacecraft can be modeled as a flat plate with solar cells covering it facing the Sun. The absorbtivity, $\alpha = 0.805$, and emissivity, $\varepsilon = 0.825$. Qs, the Solar constant in Earth orbit, = 1400 W/m^2 Qe, thermal flux from Earth = 660 W/m^2 (albedo 0.3). The Stefan-Boltzmann constant is σ. The spacecraft surface temperature is calculated to be:

Equation 1: Spacecraft Surface Temperature in Light

$$T = \sqrt[4]{\frac{Q_S \alpha}{\sigma \varepsilon} + \frac{Q_e}{\sigma}} = \sqrt[4]{\frac{1400 \times 0.805}{5.67 \times 10^{-8} \times 0.825} + \frac{660}{5.67 \times 10^{-8}}} = 434.8^0\,K$$

On the night side of the orbit only infra-red radiation from the Earth contributes to the temperature (240 W/m^2). This results in a temperature of:

Equation 2: Spacecraft Surface Temperature in Darkness

$$T = \sqrt[4]{\frac{Q_S \alpha}{\sigma \varepsilon} + \frac{Q_e}{\sigma}} = \sqrt[4]{\frac{240}{5.67 \times 10^{-8}}} = 255.1^0 K$$

Orbital Analysis

As with most CubeSat missions, the orbital parameters of the spacecraft will most likely be determined late in the design. Some assumptions can be made however. If the mission will be launched from the KSC-CCAFS launch pads the maximum orbital inclination will be about 57 degrees while polar orbit can only be attained from Vandenberg Air Force Base. All CubeSats deployed so far have been into orbits under about 1500 km.

A satellite in Low Earth Orbit will quickly track across the sky. A spacecraft in a 300 km orbit will be tracked by a ground station that can track within 5 degrees of the horizon for at most about 6 ½ minutes. If the system will consist of only one ground station, then for an average 95 minute LEO orbit, data will have to be downloaded in that brief pass. In other words, only 6 ½ minutes of data is likely to be downlinked per pass. Also the spacecraft's orbit will only typically provide perhaps 3 passes per day over one ground station.

The table below summarizes possible orbital parameters for the mission. A higher orbit will mean a longer range (distance) from the ground station to the spacecraft for communication but will increase the amount of time available for down-linking data each day. Increasing orbital altitude to 1000 km will increase data link time per day from about 20 minutes to about 22 minutes. A 1500 km orbit will provide about 24 minutes of downlink time per day for one ground station.

Table 7: Orbital Characteristics dependent on Altitude

Orbital Altitude (km)	**Max Comm Range (km)**	**Rev/day**	**Period (min)**	**Communications time(per day per station) (min)**
500	2500	15.18	94.62	20
1000	3700	13.66	105.12	22
1500	4600	12.38	115.98	24

The CubeSat has the requirement for de-orbit within 25 years of beginning its mission per the CubeSat ICD. The nanoTerminator is a tether designed to de-orbit a CubeSat within the post mission orbital lifetime restrictions at altitudes up to 1000 km. More information is available at http://www.tethers.com/nanoTerminator.html. According to information on this website, a tether is deployed at the end of the mission to increase drag. It is a flat panel sized to fit on any face of a CubeSat within the 6.5 mm envelope available beyond the rails. "At the conclusion of the CubeSat's mission, a burn-wire release mechanism will actuate the ejection of the nanoTerminator's cover, deploying a 30-m long conductive tape." See the figure below.

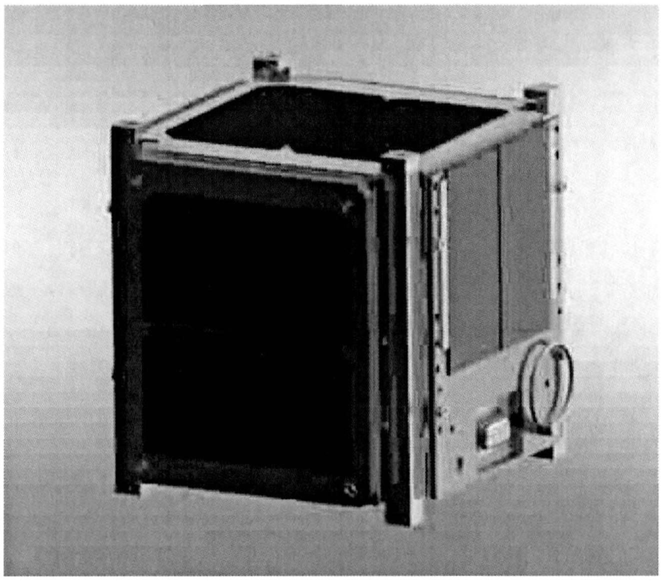


Figure 20: nanoTerminator Example

A complete orbital lifetime analysis would have to be conducted once a launch vehicle and approximate final orbital altitude is known. Issues affecting orbital lifetime include time during solar cycle majority of mission takes place, orbital inclination and of course initial orbital altitude.

Orbital debris is a growing concern in Low Earth Orbit with a peak flux under 1,000 km orbital altitude. However, the short duration of this mission and the small cross-sectional area of a CubeSat minimize this issue.

Wireless Accelerometers

Wireless Accelerometers are available from a wide range of sources. Space qualified wireless accelerometers are difficult to find in higher frequency range; however, at 4000Hz there are numerous production companies who produce an acceptable product (Bruel and Kjaer is one such example). Many of the products come ready to mount to any surface through adhesives which are capable of withstanding space conditions. The true test is to find various models with different sensitivities (in g's).

This function has been demonstrated as feasible in other industrial domains (Energy production, heavy manufacturing) to monitor rotating machines (motors, turbines) health and to be able to detect and prevent failures. Although it is usually done with wired technologies, some companies have decided to fund low power wireless systems to lower costs of installation, maintenance and operations.

Therefore, 3 types of wireless technologies that are compatible with such harsh (in terms of temperature, pressure, humidity and interference) environment have emerged. Their development stage (TRL) is relatively different, however, feasibility has been established in all 3 cases.

- Technology 1: Wireless Sensor Network (TRL 9). This technology is widely used, it is very resilient to interference thanks to DSSS technology, but the limited bandwidth might be too small to transfer in real time to the receiver all the collected data, depending on the chosen solution. In this case, the use of a buffer at the sensor level before transmission to the receiver is consequently used to achieve the 4kHz sampled data acquisition. Providers can be for instance Crossbow, Xbee or Dust Networks. Another solution from MicroStrain directly enables the 4kHz sampled data acquisition.
- Technology 2: Low Power WIFI (TRL 9). A low power version of the well known WIFI communication system has been developed especially to take into account the weaknesses of WSN, while enabling battery operated and low power wireless sensors. LP WIFI is not as resilient as WSN since it is not capable of jumping from one frequency to another one, but its resilience should be enough if sensor and receiver antennas are sufficiently close from each other. Providers include North Pole Engineering and SR Monolithics, that both use the GainSpan technology
- Technology 3: Ultra Wide Band (TRL 5 and up). This technology has initially been developed for military applications and takes its advantage on the large bandwidth of the pulse emission. The communication link consequently becomes fast and most of all highly resilient to the environment. The transfer to civilian application seems to be happening, with the expansion of wireless applications. The technology enables ultra low power, largely resilient and high bandwidth wireless communication between a sensor, such as an accelerometer, and its close receiver. Identifiable developers are Intel, Infineon, Siemens, Agilent Direct and others. However, there is still no industrial product on the market.

Wired Sensing

Acoustic Detection (optional)

Whereas it is not directly mentioned as a requirement, acoustic detection may be helpful as an option to identify or confirm a specific event during launch based upon a (perhaps matched or relatively loud) noise event. This may provide primary or supplementary information for identifying key mission events such as waking-up the on-board computer on time and triggering/confirming the acceleration and temperature sensing and recording at appropriate times. This sensor could also be used to characterize the noise environment within the CubeSat (also not required, nor evaluated as part of this effort, but potentially useful).

Proposed solutions (Akustica AKU2002C or Analog Device ADMP421) have already demonstrated this feasibility in other industrial domains (security, surveillance, automats by the use of a MEMS microphone, and its DSP board that have consumption on the order of 1.5mW, or 7W during 60 days.

Acquisition will then be achieved by the CD&H CubeSat Kit FM430, as a triggering event, and the microphone system will be turned off for the remaining of the mission. It shall then be active only from 30 days before launch to X (X>5) seconds before launch.

Wired Accelerometers

The wired accelerometers, along with the thermocouples, are among the easiest and most plentiful products to be used. There are numerous companies who provide space rated accelerometers of all sampling rates. Like the wireless accelerometers, the wired variety also comes with adhesives that allow for installment on any interior surface within the CubeSat structure which includes but is not limited to the inside of the CubeSats plated walls. However, considering the MLI thermal blanket discussed in the CubeSat Operational Environment section, it is more likely that the sensors would be attached to a circuit board which could be rigidly mounted within the confines of the CubeSats walls.

The accelerometers were selected according to:

- Measuring frequency-range (up to 10 kHz)
- Size
- Sensitivity
- Temperature

Triaxial accelerometers were considered since these could furnish acceleration during rocket lift-off, pyrotechnic events in all three spatial directions. Triaxial accelerometers are more compact than three separate accelerometers, and the cabling is simplified. A triaxial accelerometer needs one cable with 4 different wires, while three separate accelerometers need three separate cables: one cable is needed instead of three. The triaxial accelerometer chosen may be substituted with other accelerometers available from Endevco, Kistler and other vendors. The chosen accelerometer is a PCB Model 350B50 type. The chosen accelerometer is suitable for shock measurements up to 10000 g's and exhibits a frequency range of 3 to 10,000 Hz for a 1db sensitivity variation, or a 1.5 to 20000 Hz frequency range for 3 db sensitivity variations. The operating temperature is between -54^{0}C and 250^{0}C. The sensor output connects to two, 5V-USB-powered, ICP power supplies, PCB type 485B36

Figure 21: Triaxial Accelerometer Model 350B50 from PCB

Power Requirements for Triaxial Accelerometer

The power requirements for wired accelerometers are related to the signal conditioner. The triaxial accelerometer needs two ICP power supplies PCB type 485B36 (Figure 12). The power supply (or signal conditioner) conditions the voltage obtained from the sensor itself and requires 5V obtained via an USB port. Three PCB Model 002A03 cables (or equivalent), linking the accelerometer output cable to the power supplies are needed (Figure 3). One cable 009M1310 is needed per power supply (two in total) to take the output signal from the signal conditioner to the data acquisition system.

Figure 22: ICP Power Supply PCB Type 485B36

The power supply has the following characteristics:

- 5 VDC supply voltage(obtained via an USB port)
- 1 to 50k Hz frequency response (±5%)

- Provides signal conditioning for 2 ICP channels

It should be noted that the manufacturer may adapt device to needs, since the device can take only two channels; thus a special device with three channels may be manufactured upon request. The power bus on the CubeSat may be adapted to allow USB interface.

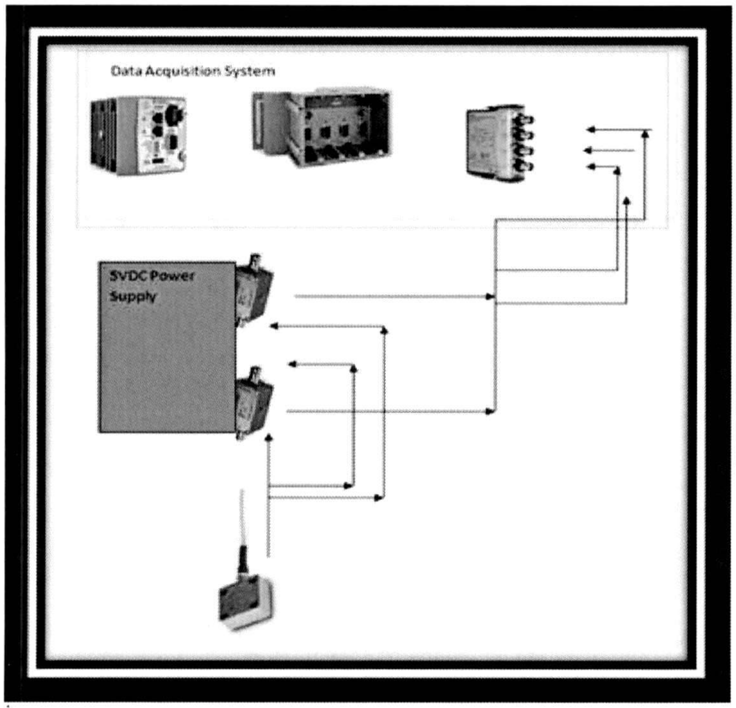


Figure 23: Wiring Diagram of Triaxial Accelerometer

Thermocouple

Due to the wide range of available thermocouples, such as the Aerospace 2 Terminal Temperature Transducer from Analog Devices, detailed in Appendix C, selection should be based on operating temperatures and accuracy of readings. As specified by the proposal document research on an accurate, reliable, space certified thermocouple taking readings at up to 25Hz has shown to be highly feasible. Further research revealed that a higher frequency may be used, due to the relatively low data storage space used by the Thermocouples. Conditioning circuitry such as an operational amp or op-amp may need to be used to send the readings to the A/D converter since thermocouples analyze samples at 1 uA/degrees Kelvin. This issue is addressed with regards to the A/D converter itself later in this document.

The feasibility of temperature measurement and acquisition onboard CubeSats has been demonstrated in each of all missions that have flown since this is a key parameter of any satellite telemetry. No specific solutions will be consequently proposed in this study. Acquisition can be achieved by the acquisition module CubeSat Kit D2 (PPM D2). It can then be stored on a 2Gb SD card plugged into the CD&H Motherboard CubeSat Kit FM430.

A/D converter

The research conducted showed that market technology is fully capable of meeting the NASA CubeSat mission requirements. There are many different space certified A/D converters and selection is based upon bit rate, conversion rate, input current range, and weight. Data storage feasibility analysis is shown for an 8-bit, 10-bit, and 12-bit A/D converter along with component weight analysis in Appendix C. Signal conditioning circuitry shown below in Figure 24, such as amplification of signal or frequency conditioning is based solely upon the final thermocouple selection.

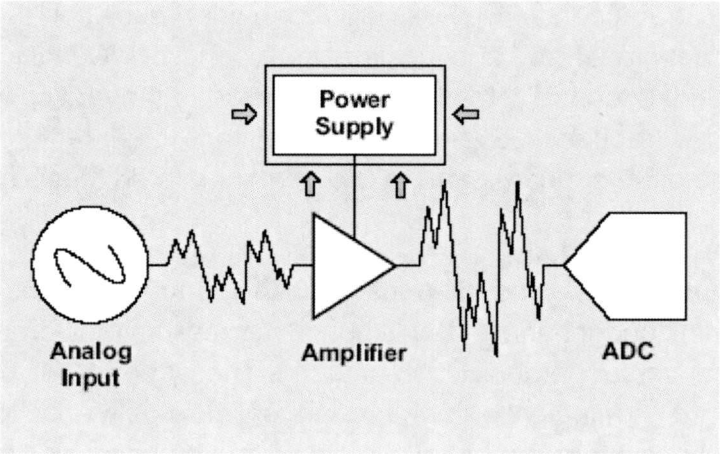


Figure 24: Signal Conditioning Circuitry

For example, a 1 micro-amp per degree Kelvin is selected. An amplifier is needed to boost the signal to a current handled by the converter such as 0.5, 2, 5 amps etc., within the temperature range of 210 to 420 degrees Kelvin, a temperature range experienced by previous CubeSat investors such as California Polytechnic State University. In this case the signal must be amplified roughly 1000 times in order to obtain a readable signal. Final A/D converter details will determine the amplifier needed within the CubeSat all of which are analyzed in Appendix C. Likewise frequency conditioning may be needed to raise the input to the correct value, i.e. 25 Hz to the 25 KHz handled by the converter all of which will be based upon the final converter specifications. The use of a space certified A/D converter given a set temperature range and requirements was found to be highly feasible.

Camera

Probability of failure for the camera is based on the use of a space certified camera. The camera components such as the video chip, processor, and A/D converter may be custom designed to save on weight, but existing technology is a very feasible option. Current market components, for example video chip, processor, optics etc., cover all technical requirements given to Florida Tech by NASA listed in the proposal document. Multiple options for Video quality, frame rate, storage capacities, and analog to digital converters are included in Appendix C. Obtaining quality video for 5 seconds before CubeSat ejection through 1 minute following CubeSat ejection (total of 65 seconds) from PPOD is highly feasible.

Though the consequences of camera failure are extreme, the probability of failure of a space certified camera within the time constraints of the proposed mission is low (See Appendix F). Feasibility for higher resolution color video chips has also been analyzed and included in Appendix C. Conditioning circuitry may also be needed to modify the input video signal to the A/D converter for storage, i.e. video frequency. Even with this circuitry, weight requirement will be met and the use of an onboard camera is determined to be feasible.

Transmission System

Several assumptions have had to be made for the communications system. The ground station link budget analysis was conducted assuming a ground station with a 4 meter diameter parabolic dish antenna. The CubeSat will be limited in terms of on-board pointing capability therefore only low gain near omni-directional antennas such as a half-wave dipole can be used. The frequency band analyzed is S-Band using FM modulation. With the use of S-Band a simple patch antenna should be possible without the need of a deployable antenna. It may be necessary for complete coverage to place the patch antennas on multiple spacecraft faces. Power for transmission is assumed to be 1 W. The CubeSat ICD requires the presence of inhibits for power levels in excess of 1.5 W.

A low Earth orbit slant range from spacecraft to ground station was estimated to be 2,500 km (see orbital analysis). The margins using FSK modulation is 5 dB for a data rate of 650 kbps. If a lower gain, Yagi style ground station antenna is used the 5 dB margin is only possible with a data rate of only 406 bps. It is evident that a larger asset than a typical CubeSat ground station (Yagi-based system) will be needed to downlink images and other data required for this mission.

For the link budgets, a qualitative estimate was made of the data generated by the mission. The main data driver is the camera images. It was assumed single images would be taken, not video at a rate of about one every three seconds. The table below summarizes the data budget. With 20 images, the rough total data volume with margin is 150,000,000 bits. A more detailed data dimensioning analysis will be presented later in this report.

Data downlink estimates were made from the link budgets for all three possible orbits, LEO, MEO, and HEO. The time it takes to downlink the data ranges from about 250 seconds to 780 seconds. For even the worst-case scenario, assuming 20 images are enough to capture all activity of interest, then a downrange downlink station with visibility of the spacecraft for about 15 minutes should be more than enough. This estimate also does not take into account any on-board compression of the imaging data. In the following link budget tables, the green elements are input parameters and the yellow elements are derived quantities.

S-band			Uplink	Downlink
Item	Symbol	Units	Command	Telemetry and Data
Frequency	f	GHz	2.67	2.52
Transmitter Power	P	Watts	75	1
Transmitter Power	P	dBW	18.8	0.0
Transmitter Line Loss	Li	dBW	-1	-1
Transmit Antenna Beamwidth	theta t	deg	2.0	135.0
Peak Transmit Antenna Gain	Gpt	dBW	38.3	1.7
Transmit Antenna Diameter	Dt	m	4.0	0.06
Transmit Antenna Pointing Offset	et	deg	0.01	1
Transmit Antenna Pointing Loss	Lpt	dBW	0.0	0.0
Transmit Antenna Gain	Gt	dBW	38.3	1.7
Equiv. Isotropic Radiated Power	EIRP	dbBW	56.0	0.7
Propagation Path Length	S	km	2500	2500
Space Loss	Ls	dB	-168.9	-168.4
Propagation & Polarization Loss	La	dB	-0.3	-0.3
Receive Antenna Diameter	Dr	m	0.06	4.0
Peak Receive Antenna Gain	Grp	dB	2.14	37.87
Receive Antenna Beamwidth	theta t	deg	127.4	2.1
Receive Antenna Pointing Error	er	deg	0.01	0.01
Receive Antenna Pointing Loss	Lpr	dB	0.00	0.00
Receive Antenna Gain	Gr	dB	2.14	37.87
System Noise Temperature	Ts	km	614	135
Data Rate	R	bps	100000	650569.6747
Eb/No (1)	Eb/No	dB	39.66	19.00
Carrier-to-Noise Density Ratio	C/No	dB-Hz	89.7	77.1
Bit Error Rate	BER	none	1.0E-05	1.0E-04
Required Eb/No (2)	Req Eb/No	dB	13	12
Implementation Loss (3)	none	dB	-2	-2
Margin	none	dB	24.66	5.00

Table 8: LEO Link Budget with a 4M ground station

S-band			Uplink	Downlink
Item	Symbol	Units	Command	Telemetry and Data
Frequency	f	GHz	2.67	2.52
Transmitter Power	P	Watts	75	1
Transmitter Power	P	dBW	18.8	0.0
Transmitter Line Loss	Li	dBW	-1	-1
Transmit Antenna Beamwidth	theta t	deg	1.0	135.0
Peak Transmit Antenna Gain	Gpt	dBW	8.0	1.7
Transmit Antenna Diameter	Dt	m	0.1	0.06
Transmit Antenna Pointing Offset	et	deg	0.01	1
Transmit Antenna Pointing Loss	Lpt	dBW	0.0	0.0
Transmit Antenna Gain	Gt	dBW	8.0	1.7
Equiv. Isotropic Radiated Power	EIRP	dbBW	25.7	0.7
Propagation Path Length	S	km	2500	2500
Space Loss	Ls	dB	-168.9	-168.4
Propagation & Polarization Loss	La	dB	-0.3	-0.3
Receive Antenna Diameter	Dr	m	0.06	0.10
Peak Receive Antenna Gain	Grp	dB	2.14	5.83
Receive Antenna Beamwidth	theta t	deg	127.4	83.3
Receive Antenna Pointing Error	er	deg	1	1
Receive Antenna Pointing Loss	Lpr	dB	0.00	0.00
Receive Antenna Gain	Gr	dB	2.14	5.83
System Noise Temperature	Ts	K	614	135
Data Rate	R	bps	1644.720683	406.3343467
Eb/No (1)	Eb/No	dB	27.22	19.00
Carrier-to-Noise Density Ratio	C/No	dB-Hz	59.4	45.1
Bit Error Rate	BER	none	1.0E-05	1.0E-04
Required Eb/No (2)	Req Eb/No	dB	13	12
Implementation Loss (3)	none	dB	-2	-2
Margin	none	dB	12.22	5.00

Table 9: LEO Link Budget with Yagi Ground Station

S-band			Uplink	Downlink
Item	Symbol	Units	Command	Telemetry and Data
Frequency	f	GHz	2.67	2.52
Transmitter Power	P	Watts	75	1
Transmitter Power	P	dBW	18.8	0.0
Transmitter Line Loss	Li	dBW	-1	-1
Transmit Antenna Beamwidth	theta t	deg	2.0	135.0
Peak Transmit Antenna Gain	Gpt	dBW	38.3	1.7
Transmit Antenna Diameter	Dt	m	4.0	0.06
Transmit Antenna Pointing Offset	et	deg	0.01	1
Transmit Antenna Pointing Loss	Lpt	dBW	0.0	0.0
Transmit Antenna Gain	Gt	dBW	38.3	1.7
Equiv. Isotropic Radiated Power	EIRP	dbBW	56.0	0.7
Propagation Path Length	S	km	3700	3700
Space Loss	Ls	dB	-172.3	-171.8
Propagation & Polarization Loss	La	dB	-0.3	-0.3
Receive Antenna Diameter	Dr	m	0.06	4.0
Peak Receive Antenna Gain	Grp	dB	2.14	37.87
Receive Antenna Beamwidth	theta t	deg	127.4	2.1
Receive Antenna Pointing Error	er	deg	0.01	0.01
Receive Antenna Pointing Loss	Lpr	dB	0.00	0.00
Receive Antenna Gain	Gr	dB	2.14	37.87
System Noise Temperature	Ts	K	614	135
Data Rate	R	bps	100000	296973.0635
Eb/No (1)	Eb/No	dB	36.26	19.00
Carrier-to-Noise Density Ratio	C/No	dB-Hz	86.3	73.7
Bit Error Rate	BER	none	1.0E-05	1.0E-04
Required Eb/No (2)	Req Eb/No	dB	13	12
Implementation Loss (3)	none	dB	-2	-2
Margin	none	dB	21.26	5.00

Table 10: Medium Earth Orbit Link Budget

S-band			Uplink	Downlink
Item	Symbol	Units	Command	Telemetry and Data
Frequency	f	GHz	2.67	2.52
Transmitter Power	P	Watts	75	1
Transmitter Power	P	dBW	18.8	0.0
Transmitter Line Loss	Li	dBW	-1	-1
Transmit Antenna Beamwidth	theta t	deg	2.0	135.0
Peak Transmit Antenna Gain	Gpt	dBW	38.3	1.7
Transmit Antenna Diameter	Dt	m	4.0	0.06
Transmit Antenna Pointing Offset	et	deg	0.01	1
Transmit Antenna Pointing Loss	Lpt	dBW	0.0	0.0
Transmit Antenna Gain	Gt	dBW	38.3	1.7
Equiv. Isotropic Radiated Power	EIRP	dbBW	56.0	0.7
Propagation Path Length	S	km	4600	4600
Space Loss	Ls	dB	-174.2	-173.7
Propagation & Polarization Loss	La	dB	-0.3	-0.3
Receive Antenna Diameter	Dr	m	0.06	4.0
Peak Receive Antenna Gain	Grp	dB	2.14	37.87
Receive Antenna Beamwidth	theta t	deg	127.4	2.1
Receive Antenna Pointing Error	er	deg	0.01	0.01
Receive Antenna Pointing Loss	Lpr	dB	0.00	0.00
Receive Antenna Gain	Gr	dB	2.14	37.87
System Noise Temperature	Ts	K	614	135
Data Rate	R	bps	100000	192158.5492
Eb/No (1)	Eb/No	dB	34.36	19.00
Carrier-to-Noise Density Ratio	C/No	dB-Hz	84.4	71.8
Bit Error Rate	BER	none	1.0E-05	1.0E-04
Required Eb/No (2)	Req Eb/No	dB	13	12
Implementation Loss (3)	none	dB	-2	-2
Margin	none	dB	19.36	5.00

Table 11: High Earth Orbit Link Budget

Orbit	Downlink Time (sec)
LEO	250
MEO	505
HEO	781

Table 12: Estimated Downlink Time

The Tracking and Data Relay System (TDRS) network was also analyzed as a possible communications platform. This Geosynchronous communications satellite network is operated by NASA. There is a new CubeSat compatible TDRS transponder called CSR-SDR (www.vulcanwireless.com). This system uses the TDRS S-band communications link. It would allow data to be sent as long as the TDRS assets are available to the project. TDRS can be highly subscribed so availability may need to be negotiated. The image below shows the CSR-SDR flight experiment that flew on a sounding rocket from New Mexico in May, 2010 to an altitude of 115 km. This system does not yet appear to be in production so its readiness for a mission is still in doubt.

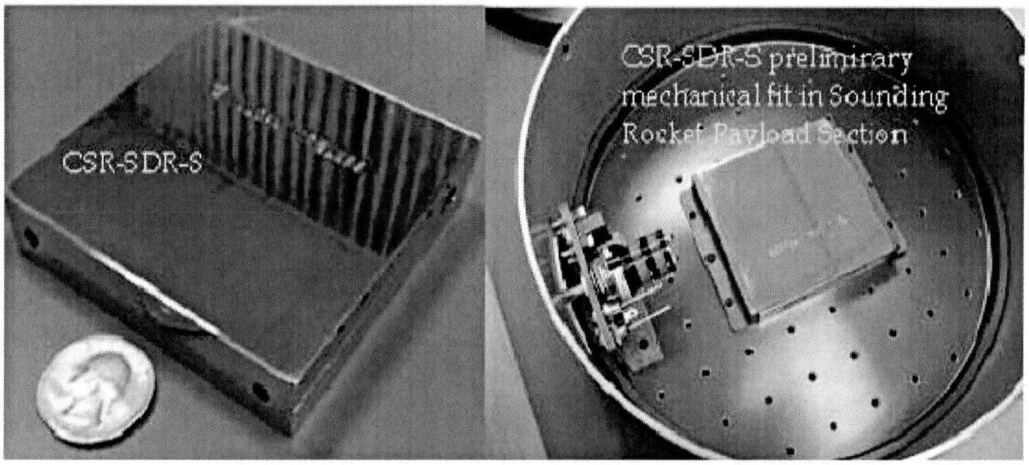


Figure 25: TDRS-compatible Flight Experiment

The Iridium satellite network was also considered. However, their transponders require about 27 Watts of power. This is not realistic for this mission scenario. An Iridium transponder would also most likely need software/firmware modifications to account for Doppler shift for space orbital velocity use.

A license will need to be applied for, most likely through the NTIA, the US government agency's frequency management office. Amateur bands were identified as not useable for this project due to the ULA-proprietary nature of the downlink data. This licensing process can be lengthy and should be started as soon as possible.

Data Dimensioning

Table 13 shows the summary information for estimating the size of the data that needs to be transmitted from the CubeSat to the ground. Both compressed and uncompressed results are shown. For the video and data compression row, the "Size/event (bits)" column was determined using an engineering model for a 640 by 480 camera. Other pixel size cameras are readily available and may be picked during a subsequent design phase after a suitable trade study.

	Sampling (Hz)	Resolution (bits)	Size/s (bps)	Size/event (bits)									Uncompressed	Compressed
Telemetry			N/A										2000	
Video and data compression		640*480	600000									39000000	39000000	39000000
Thermal Sensors (Wired, 25Hz)	25	10	250	2500	43750	1250						16250	63750	1593.75
Vibration Sensors (Wired, 25kHz)	25000	10	250000	2500000		1250000	1250000	2500000	1250000	1250000	1250000	16250000	27500000	687500
Vibration Sensors (Wired, 4kHz)	4000	10	40000	400000	7000000	200000						2600000	10200000	255000
Vibration Sensors (Wireless, 4kHz)	4000	10	40000	400000	7000000	200000						2600000	10200000	255000
Planned Mission Life 24 Hours				Launch T_0-5	Boost Ph. T_0+5	Boost Sep. T_0+180	Fairing Sep T_1	2nd Stage SD: T_2	3rd Stage Igni.: T_3	3rd Stage SD: T_4	Primary Sep T_5	CS ejection T_6 5s		
													Total size	40199093.75

Table 13: Potential Data Collected and Transmitted

Data acquisition can be achieved either directly on the main CD&H module for the low sampling rates, and on the specific acquisition module that has a 500ksamples/s acquisition capacity for the vibration data. Proposed solutions were discussed in the "CD&H and Acquisition Feasibility, Architecture, and Performance Options" section of this report.

Video signals and data signals may then be compressed in real time through a specific FPGA compression card developed for CubeSat missions.

Two Solutions are identified to achieve communication functions and performance in the transmission of the recorded data within 24 hours after launch.

Theoretical calculations demonstrate 654kbps are achievable with NASA ground systems at the Kennedy Space Center.

These 2 solutions are already qualified and have already flown in CubeSat missions.

- Solution 1: EMHISER EDTI P5E1A102-00, that will enable a 654kbps downlink data rate
- Solution 2: Clyde-Space S-Band Transmitter, that will enable a 115kbps downlink data rate

Data rate (kbps)	650	115
Video scenario DL time	1m02s (1 pass)	5m50s (2 passes)
Picture scenario DL time	17s (1 pass)	1m48 (1 pass)

Table 14: Estimated Downlink Time

Command reception and beacon functions can also be achieved with the following devices:

- Receiver
- Beacon

Autonomous Data Acquisition Sub-System

This study has focused on the feasibility of the provided requirements as applied to a CubeSat-based system solution. The primary mission of the subject CubeSat is to collect data from various sensors at pre-selected points within the mission timeline. The sensor subsystem will collect shock, vibration, temperature and video data during the mission.

A particularly challenging requirement is that the system shall collect sensor data at the point of ignition of the main rocket engines as the launch vehicle is ignited for its journey into space. In order to capture the "instant of ignition" the sensor network will have to be acquiring data prior to ignition. This is challenging because the CubeSat will have no knowledge of the exact launch time and will have no means of using external electrical power once installed into the P-POD launcher by the payload integrator. This could mean 30 days or more between when the build team last touches the CubeSat and when the actual launch occurs. This situation presents two key technical issues that must be overcome: acquiring telemetry data for a launch event that is not exactly known, and managing electrical power over an indeterminate "wait-for-launch" period. These challenges have been considered and potential solutions are discussed here.

Data Acquisition

In order to capture the telemetry data (shock and vibration) at the instant the rocket engines fire, the data acquisition system needs to be collecting data just prior to the event. Since the actual event cannot be accurately predicted, the system must be capable of collecting data continuously and identifying the correct time to store the data, while all other data is discarded. One solution is the use of pre-triggering, similar to that of a digital storage oscilloscope. The system would use a buffer of perhaps 1 second worth of data, and push old data out as new data is collected. In the event that the launch is detected, the system would extract from the buffer the event, plus a short period before and after. In this way, the event can be captured without the delay of having to power up the acquisition system and begin recording data.

Power Management

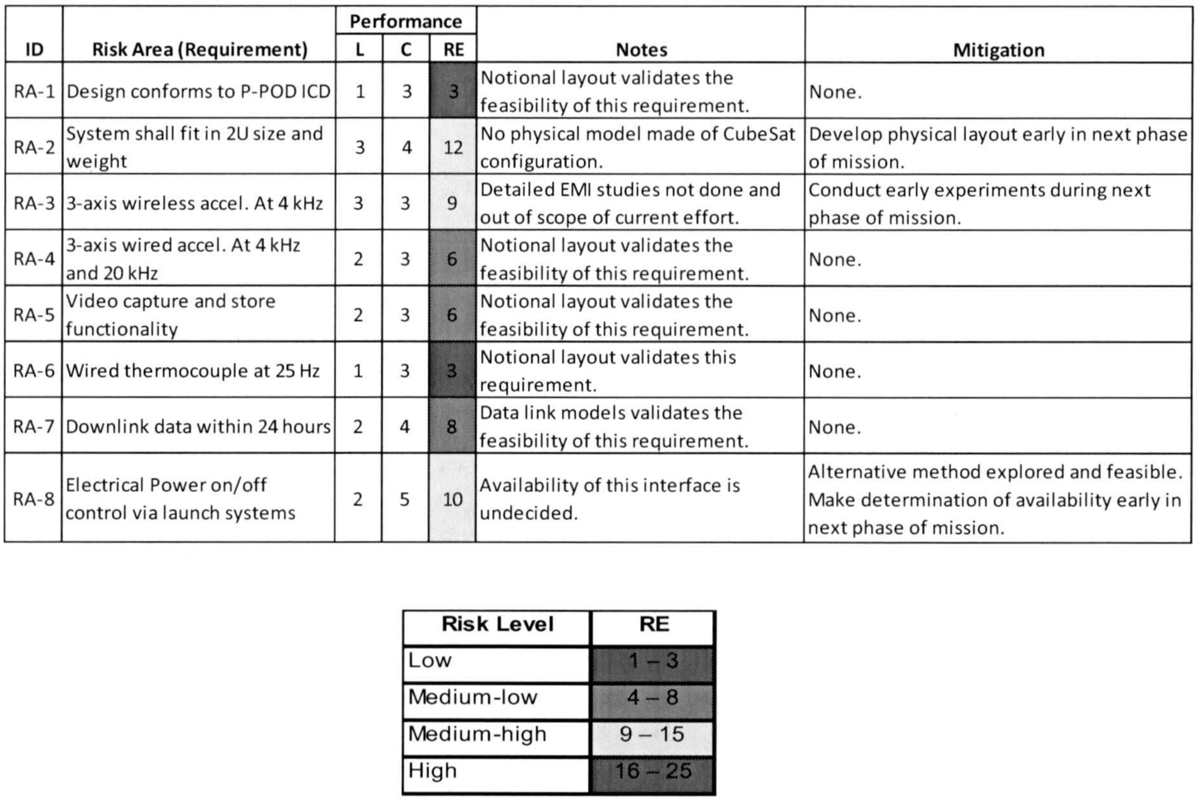
In order to implement the data acquisition strategy discussed above, the CubeSat must be capable of operating in a low-power or sleep mode to maximize battery life. In one conceptualized solution the CubeSat incorporates an autonomous micro-controller based data acquisition system that is wholly independent of the primary on board computer, data acquisition and electrical power systems. The system would include its own battery, accelerometer and data storage mechanism. In using a separate system to detect and capture the launch event, the primary battery power is preserved to execute the mission requirements subsequent to the actual launch event. The addition of a separate subsystem directly impacts the size, weight and power budget of the primary CubeSat payload. To this end, the system must be carefully selected and integrated. For example, a micro-controller device such as the Texas Instruments MSP430 family draws only 0.7uA in sleep mode and can run for up to one year on a single AA battery using power saving programming techniques. Similarly, a low power sensor would be required to collect the launch induced vibration and shock data. A device such as the Analog Devices ADXL346 3-axis accelerometer draws only 0.2uA in sleep mode. In a typical scenario, the entire subsystem could be integrated on a single PWB measuring less than 3 square inches. The system would alternate between wake and sleep modes to conserve power and maximize operational duration. In operation, the system would wake up, check for vibration and then go back to sleep. If vibration data (launch) is present the data is stored and then the system goes back to sleep. The stored data is transferred to the primary mission data storage system later in the mission.

Post Deployment Separation

With regards to the separation distance of the 1U and 2U CubeSat one minute after ejection/deployment from the P-POD, and its impact on potential post deployment communications between the 1U and 2U CubeSat, we do not believe this to be a significant issue. According to a student paper from Stanford, (http://ssdl.stanford.edu/ssdl/images/stories/papers/2000/ssdl0002.pdf page 13), the launch speed of one CubeSat out of the P-POD is listed at 0.3 m/s. Since the launch is going to be in space, where there is not much friction, the spatial separation between two CubeSats is going to be the product of the delay between the launch of each CubeSat out of the tube (time) and the release velocity (0.3 m/s) . The release velocity could be controlled via the stiffness of the spring (which could be selected later during the design stage). For example, if the release mechanism would be designed to give a 1 second time delay, the separation would be 0.3 m. The transmission will be only for a short time after release, thus there will be no significant effects due to orbital decay, sun particle pressure etc. If the CubeSats are released at the same time, then the separation would be non-existent. Other mitigating steps such as a tether could also be considered and evaluated during a subsequent (to this effort) design phase.

System Feasibility

From the sections above, each component has been researched, considered and measured. Each individual sub-component can be constructed feasibly within the CubeSat. From a component perspective, the proposed CubeSat experiment is considered feasible with the associated risks presented in the risk section above and repeated here for convenience.



ID	Risk Area (Requirement)	Performance L	C	RE	Notes	Mitigation
RA-1	Design conforms to P-POD ICD	1	3	3	Notional layout validates the feasibility of this requirement.	None.
RA-2	System shall fit in 2U size and weight	3	4	12	No physical model made of CubeSat configuration.	Develop physical layout early in next phase of mission.
RA-3	3-axis wireless accel. At 4 kHz	3	3	9	Detailed EMI studies not done and out of scope of current effort.	Conduct early experiments during next phase of mission.
RA-4	3-axis wired accel. At 4 kHz and 20 kHz	2	3	6	Notional layout validates the feasibility of this requirement.	None.
RA-5	Video capture and store functionality	2	3	6	Notional layout validates the feasibility of this requirement.	None.
RA-6	Wired thermocouple at 25 Hz	1	3	3	Notional layout validates this requirement.	None.
RA-7	Downlink data within 24 hours	2	4	8	Data link models validates the feasibility of this requirement.	None.
RA-8	Electrical Power on/off control via launch systems	2	5	10	Availability of this interface is undecided.	Alternative method explored and feasible. Make determination of availability early in next phase of mission.

Risk Level	RE
Low	1 – 3
Medium-low	4 – 8
Medium-high	9 – 15
High	16 – 25

Figure 26: Overall System Feasibility

Blue and green items in the table above are deemed “feasible” and low risk. The yellow items require further explanation. The requirement RA-2 is currently considered feasible but the notional components selected are within 282 grams of the 1.8Kg threshold and so somewhat of a consideration. The RA-3 Wireless Accelerometer is yellow because we have not done an EMI characterization test (part of the potential design effort) that looks at multi-path and internal to the CubeSat interference effects. This issue should be experimentally addressed early on in the design phase. The requirement RA-8 is not deemed feasible at this time because we believe that the waiver process to alter the P-POD to accept electrical signals as well as supplying power from the vehicle to the P-POD would initially be prohibitive. From a strict technical perspective, this should be possible given enough motivation and support from CubeSat experiment stakeholders. However, we believe that a timing circuit that is entirely internal to the CubeSat could feasibly satisfy the intent of this requirement and so an alternate approach is feasible.

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[2] NASA Standard Technical Standard 7002, Payload Test Requirements, July 10, 1996.

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Appendices

Appendix A: Requirements Analysis

To complete an entire requirements analysis, each operational requirement must be broken down into functional and organic requirements. Each requirement relates to the parent and sister requirements. The table below breaks the original six operational requirements discussed previously and decomposes them to the lowest level. In all there are 86 requirements listed below.

Each requirement is labeled as operational, functional, or organic. They are numbered according to their relationships, named and the requirement is then stated in the next column.

Req Type	Req Call-Out	Name	Detail	Parent	Daughter	Sister
Operational	0	CubeSat Mission Req.	The system shall comply with the Flight Mission and Design Requirements in the CubeSat to P-POD ICD.		0.1, 0.2, 0.3, 0.4, 0.5	
Functional	0.1	Holistic Design	The CubeSat shall be self-contained.	0		
Functional	0.2	Power	The CubeSat shall supply electircal power to its components.	0		
Functional	0.2.1	Power Duration	The Cubesat shall power all necessary components for the duration of their usage.	0.2		3.2, 3.3, 3.4, 4, 5
Organic	0.2.2	Power Connection	The 2U CubeSat unbilical connectors that require access following P-POD integration shall be within the green access ports in Figure 7 on page 17 of the CubeSat to P-POD ICD.	0.2		
Organic	0.2.3	Remove Before Flight Pin	The CubeSat shall be equipped with a Remove Before Flight (RBF) Pin	0.2	0.2.3.1, 0.2.3.2, 0.2.3.3, 0.2.3.4	
Organic	0.2.3.1	RBF Pin Location	The RBF Pin shall be within the green access port locations per Figure 7.	0.2.3		
Organic	0.2.3.2	RBF Pin Removal	The RBF Pin shall be removed once integrated into the P-POD.	0.2.3		
Functional	0.2.3.3	RBF Functionality	The RBF Pin shall cut all power to the CubeSat bus once inserted in the CubeSat.	0.2.3		
Organic	0.2.3.4	RBF Size	The RBF Pin shall not exceed 6.5mm normal to the surface of the CubeSat.	0.2.3		
Organic	0.3	Payload Restrictions	The CubeSat shall comply with the Flight and Mission Design Component Restrictions.	0	0.3.1, 0.3.2, 0.3.3, 0.3.4	
Organic	0.3.1	Pressure Vessels	The CubeSat shall not contain pressurized vessels.	0.3		
Organic	0.3.2	Propulsion Systems	The CubeSat shall not contain propulsion systems.	0.3		
Organic	0.3.3	Radioactive Material	The CubeSat shall not contain radioactive material.	0.3		
Organic	0.3.4	Explosive Devices	The CubeSat shall not contain explosive devices.	0.3		
Organic	0.4	Orbital Debris	CubeSat mission design and hardware shall be in accordance with NPR 8715.6A, NASA Procedural Requirements for Limiting Orbital Debris.	0		
Organic	0.5	Range Safety	CubeSat's hazardous material shall conform to AFSPCMAN 91 - 710, Range Safety User Requirements Manual Volume 3 - Launch Vehicles, Payloads, and Ground Support Systems Requirements.	0		
Operational	1	Mechanical Req.	The system shall comply with the Mechanical Requirements of the associated CubeSat mission.		1.1, 1.2, 1.3, 1.4	
Organic	1.1	Dimensions Req.	the CubeSat shall be of the 2U configuration.	1	1.1.1, 1.1.2, 1.1.3, 1.1.4, 1.1.5	
Organic	1.1.1	Dimensions	The 2U CubeSat shall be configured and dimensioned per Figure 2 on page 10 of the CubeSat to P-POD ICD.	1.1		
Organic	1.1.2	Protrusion Envelope	Components on the green and yellow shaded sides of Figure 2 shall not excood 6.5 millimeters normal to the surface.	1.1		
Organic	1.1.3	Coordinate System	The 2U CubeSat shall use the coordinate system as defined in Figure 2 of the CubeSat to P-POD ICD. The origin of the 2U CubeSat is located at the geometric center of the system.	1.1		
Organic	1.1.4	Reference Coordinates	The P-POD shall use the coordinate system as defined in Figure 4 on page 12 of the CubeSat to P-POD ICD.	1.1		
Organic	1.1.5	CubeSat Orientation	The -Z face of the CubeSat will be inserted first into the P-POD.	1.1		
Organic	1.2	Mass Req.	The CubeSat shall comply with the Mechanical Design Mass Properties listed in the CubeSat to P-POD ICD.	1	1.2.1, 1.2.2, 1.2.3	
Organic	1.2.1	CalPoly Mass Properties	At no later than L-120 days prior to launch, Cal Poly shall use the delivered CubeSat mass properties as the final mass properties statements.	1.2		
Organic	1.2.2	Placement of Mass	All CubeSat mass properties shall be expressed in the respective CubeSat coordinate system.	1.2		
Organic	1.2.3	Mass Properties Specification	The CubeSat mass and center of gravity shall comply with the CubeSat to P-POD ICD.	1.2	1.2.3.1, 1.2.3.2	
Organic	1.2.3.1	Mass	The CubeSat mass shall be between 1.8 and 2 kilograms.	1.2.3		
Organic	1.2.3.2	Center of Gravity	The 2U CubeSat center of gravity shall be at the geometric center of the system with 20 millimeter tolerances in each coordinate direction.	1.2.3		

Organic	1.3	Deployment Req.	The 2U CubeSat shall comply with the deployment criteria listed in the CubeSat to P-POD ICD.	1	1.3.1, 1.3.2, 1.3.3, 1.3.4,	
Organic	1.3.1	CubeSat-P-POD Contact	Exterior CubeSat compponents shall not contact the interior surface of the P-POD other than the designated CubeSat rails.	1.3		
Organic	1.3.2	CubeSat Rail Material	The CubeSat rails and standoffs shall be hard anodized aluminum.	1.3		
Organic	1.3.3	Separation Springs	The 2U CubeSat will use separation springs with characteristics defined in Table2 on page 14 of the CubeSat to P-POD ICD.	1.3	1.3.3.1, 1.3.3.2	
Organic	1.3.3.1	Spring Location	The 2U CubeSat separation springs shall be centered on the end of the standoff on the CubeSat's -Z face.	1.3.3		
Organic	1.3.3.2	Spring Compressed State	The compressed separation springs shall be at or below the level of the standoff.	1.3.3		
Organic	1.3.4	CubeSat Venting	The CubeSat shall be designed to accommodate adcent venting per ventable volume/area less than 2000 inches in accordance with JPL D-26086, Revision D, Environment Requirements Document (EFD).	1.3		
Organic	1.4	Material Selection Req.	The CubeSat shall conform to the material standards stated in the Cube Sat to P-POD ICD.	1	1.4.1	
Organic	1.4.1	Technical Standards	CubeSat materials shall be selected in accordance with NASA-Technical-STD-6016 (Section 4.2).	1.4		
Organic	1.4.2	Contamination Control Req.	The P-POD and all CubeSat componetns will adhere to the requirements contained in MIL-STD-1246C Product Cleanliness Levels and Contamination Control Program.	1.4		3.1
Operational	2	Environments Req.	The CubeSat shall be tested unner specific conditions to ensure survivability during the integration process at Cal Poly, the transportation to the launch site and powered flight.		2.1, 2.2, 2.3	
Organic	2.1	RF Raditation Req.	The CubeSat shall be capable of withstanding radiation tests to be determined by the Cal Poly Program Lead.	2		3.1
Organic	2.2	Structural Survivability Req.	The CubeSats shall be structurally adequate to survive the dynamic qualification and acceptance testing.	2	2.2.1, 2.2.2, 2.2.3, 2.2.4	3.1
Organic	2.2.1	Random Vibration	The CubeSat shall test, in each axis, the predicted random bibration levels at the P-POD to LV mechanical interface.	2.2	2.2.1.1	
Organic	2.2.1.1	Vibration Table Interface	Cal Poly shall provide a TestPOD as an interfac3e between the CubeSat and vibration table to simulate the environment inside the P-POD.	2.2.1		
Organic	2.2.2	Thermal Vaccuum Bakeout	CubeSats shall perform a thermal vaccuum bakeout at a high vaccuum level (minimum 1x10^-4 Torr).	2.2	2.2.2.1	
Organic	2.2.2.1	Cubesat Bakeout Profile	The CubeSat shall test to one of the two bakeout profiles seen in Figure 9 on page 21 of the CubeSat to P-POD ICD.	2.2.2	2.2.2.1.1, 2.2.2.1.2	
Organic	2.2.2.1.1	Standard Bakeout Profile	The CubeSat shall hold a temperature of 70 degress Celcius for three hours as shown in Figure 9.	2.2.2.1		
Organic	2.2.2.1.2	Extended Bakeout Profile	The CubeSat shall hold a temperature of 60 degrees Celcius for six hours as shown in Figure 9.	2.2.2.1		
Organic	2.2.3	Shock Testing	The CubeSat shall test, in each axis and both directions, the predicted shock levels at the P-POD to LV mechanical interface.	2.2		
Organic	2.2.4	Sine Vibration	The CubeSat shall perform a sine sweep to the levels in Table 3 on page 21 of the CubeSat to P-POD ICD before and after each random vibration test in all three axes.	2.2		
Organic	2.3	Characteristics Survey Req.	The CubeSat shall provide sifficient data to complete the CubeSat Transmitter Characteristics Survey to be supplied by Cal Poly.	2		
Op & Func	3	Sensor Req.	The CubeSat shall gather environmental data from three sensor sources.		3.1, 3.2, 3.3, 3.4	
Organic	3.1	Sensor Environment Req.	All sensors shall be capable of functioning during the conditions applied during the Cal Poly Environments Evaluations.	3		1.4.2, 2.1, 2.2
Functional	3.2	Vibration Measurement Req.	The CubeSat shall gather vibration data through the use of wired and wireless accelerometers.	3	3.2.1, 3.2.2, 3.2.3, 3.2.4, 3.2.5	.02.1
Organic	3.2.1	Wired Accelerometers	The CubeSat shall gather two sets of wired accelerometer data.	3.2	3.2.1.1, 3.2.1.2	
Functional	3.2.1.1	High Frequency Wired Accelerometer	The system shall be capable of acquiring and storing wired accelerometer data in 3 mutually orthogonal axes at a minimum simpling rate of 25,000 Hz.	3.2.1		
Functional	3.2.1.2	Low Frequency Wired Accelerometer	The system shall be capable of acquiring and storing wired accelerometer data in 3 mutually orthogonal axes at a minimum simpling rate of 4,000 Hz.	3.2.1		
Organic	3.2.2	Wireless Accelerometers	The CubeSat shall gather one set of wireless accelerometer data.	3.2	3.2.2.1	
Functional	3.2.2.1	Wireless Acelerometer	The system shall be capable of acquiring and storing wireless accelerometer data in 3 mutually orthogonal axes at a minimum simpling rate of 4,000 Hz.	3.2.2		
Organic	3.2.3	Accelerometer Mounting	The accelerometers shall be mounted to a rigid plane within the CubeSat.	3.2		
Organic	3.2.4	Wireless Receiver Mounting	The receiver for the wireless accelerometers shall be mounted to a rigid plane within the CubeSat.	3.2		
Functional	3.2.5	Accelerometer Recording Time	The accelerometers shall record vibration data from 5 seconds prior to launch through 1 minute after ejection.	3.2		
Functional	3.3	Temperature Measurement Req.	The CubeSat shall gather one set of data from a thermocouple.	3	3.3.1, 3.3.2, 3.3.3	0.2.1
Organic	3.3.1	Thermocouple Mounting	The thermocouple shall be mounted to a rigid plane within the CubeSat.	3.3		
Functional	3.3.2	Low Frequency Thermocouple	The system shall be capable of acquiring and storing thermocouple data within the CubeSat System at a minimum sampling rate of 25 Hz.	3.3		
Functional	3.3.3	Thermocouple Recording Time	The thermocouple shall record thermal data from 5 seconds prior to launch through 1 minute following ejection.	3.3		
Functional	3.4	Video Capture Req.	The CubeSat shall be capable of storing and transmitting recorded video data.	3	3.4.1, 3.4.2, 3.4.3	0.2.1
Organic	3.4.1	Video Camer Mounting	The video camera shall be mounted on a rigid plane within the CubeSat.	3.4		
Organic	3.4.2	Camera Orientation	The camera shall be oriented longitudinally along the -Z axis.	3.4		
Functional	3.4.3	Camera Recording Time	The camera shall record video data from T-5 seconds prior to ejection from P-POD to 60 seconds after ejection.	3.4		
Functional	3.4.4	Video Camera Illumination	The CubeSat shall illuminate the space being recorded for the duration of the recording process.			

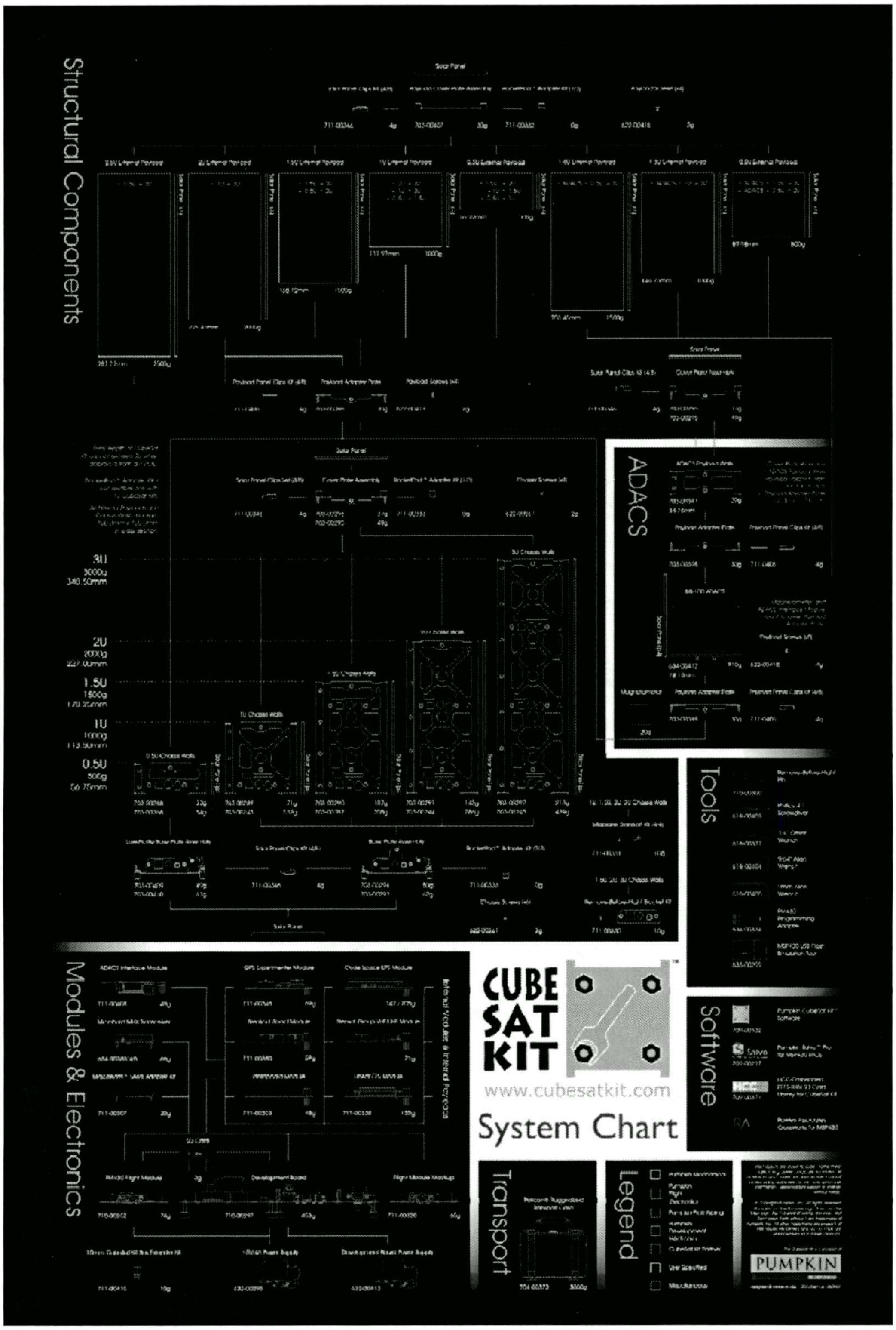
Op & Func	4	DSP Req.	The system shall be capable of gathering and storing data recorded by the sensors.		4.1, 4.2,	0.2.1
Functional	4.1	Data Acquisition	The system shall receive data from the sensors (accelerometers, thermocouple and video camera).	4	4.1.1, 4.1.2	
Functional	4.1.1	Signal Conditioning	The data recorded by the accelerometers shall be conditioned to the proper characteristics prior to storage.	4.1		
Functional	4.1.2	Analog to Digital Conversion	Any analog data shall be converter from analog to digital prior to storage.	4.1		
Functional	4.2	Data Processing	All recorded data shall be stored on-board.	4	4.2.1, 4.2.2, 4.2.3	
Functional	4.2.1	Data Storage Unit	The on-board data storage unit shall be capable of receiving multiple inputs simultaneously.	4.2		
Organic	4.2.2	Storage Unit Mounting	The on-board data storage unit shall be mounted to a rigid plane within the CubeSat	4.2		
Functional	4.2.3	Data Recall	The stored data shall be capable of being recalled for downlinking.	4.2		
Op & Func	5	Communication Req.	The system shall be capable of relaying stored data from the CubeSat.		5.1, 5.2, 5.3	0.2.1
Functional	5.1	Data Retrieval	The system shall retrieve data from the on-board storage unit	5		
Functional	5.2	Data Transmission	The system shall deliver the data to its final destination at NASA Hangar AE on CCAFS.	5	5.2.1, 5.2.2	
Organic	5.2.1	Transmission Locations	The CubeSat shall downlink to multiple ground locations.	5.2		
Organic	5.2.2	Tranmission Frequency	The CubeSat shall operate within an acceptable transmission frequency range to comply with all ground station antennas.	5.2		
Functional	5.3	Transmission Time Frame	The system shall deliver the data to Hangar AE within 24 hours of ejection from P-POD.	5		

Table 15: Derived Requirements found through Decomposition of User Needs

The daughter and sister columns link multiple requirements from one operational branch to another. These are used to show that some requirements, while not explicitly related to a subject, are heavily dependent on a requirement from another section of the requirements. In this instance, the Power Duration requirement (0.2.1) is directly related to the functional requirements governing the sensor, DSP, and communication systems.

Appendix B: Potential Components

Chassis



CD&H

http://www.cubesatkit.com/

CubeSat Kit™ Motherboard (MB)

Hardware Revision: D

Single Board Computer Motherboard for Harsh Environments

Applications

- CubeSat nanosatellite C&DH, TT&C, mass storage and battery / power switching
- General-purpose low-power computing in a PC/104-size form factor
- Remote sensing for harsh environments

Features

- Open architecture – accepts Pluggable Processor Modules (PPMs)
- Compatible with a wide range of supply and I/O voltages
- Extremely low (<10µA) quiescent current
- Integrated peripherals:
  - I2C real-time clock
  - 3V Lithium backup battery
  - USB 2.0 device interface for pre-launch communications, battery charging and power
  - MMC/SD card socket for mass storage (32MB to 2GB and beyond)
- Support for a wide range of transceivers
- Stackable 104-pin CubeSat Kit Bus connectors includes processor's complete I/O space, user-assignable signals and more
- Extensible to multiprocessor architectures, with processor reset / NMI pin on bus
- Direct wiring for heavy-duty Remove-Before-Flight and Deployment switches
- Comprehensive overcurrent, overvoltage & undervoltage (reset) protection
- Independent latchup (device overcurrent) protection on critical subsystems
- Bus override for critical power and data/control paths
- Power consumption can be monitored externally
- Wiring-free module interconnect scheme
- PC/104-size footprint, with +5V and GND on PC/104 J1/J2 connectors
- 6-layer gold-plated blue-soldermask PCB with dual ground planes for enhanced signal integrity
- Compatible with Pumpkin's Salvo™ RTOS and HCC-Embedded's EFFS-THIN SD Card file FAT file system for ease of programming
- Backwards-compatible with CubeSat Kit Rev. A through Rev. C FM430

ORDERING INFORMATION

Pumpkin P/N 710-00484

Option Code	PPM Connector Height	CubeSat Kit Bus Connector[1]
/00 (standard)	+6mm	non-stackthrough
/10	+6mm	stackthrough

Contact factory for availability of optional configurations. Option code /00 shown.

CAUTION

Electrostatic Sensitive Devices

Handle with Care

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[1] Stackthrough connectors are used in CubeSat Kit configurations where the MB is not in Slot 0.

OPERATIONAL DESCRIPTION

The CubeSat Kit Motherboard (MB) is the fourth generation of Pumpkin's line of single-board computers (SBCs) designed for use in the CubeSat Kit and elsewhere.

Unlike earlier Pumpkin SBCs like the FM430[2], the MB does not have a permanently soldered processor.[3] Instead, it has a socket to accommodate a Pluggable Processor Module (PPM). PPMs can be sourced from Pumpkin, third parties or can be created by the end-user of a CubeSat Kit. Thus, a wide range of potential processors (e.g. MSP430, 8051, AVR®, PICmicro®, ARM®, x86, FPGA, ASIC, etc.) can be used with the MB via a suitable PPM.

The MB has a flexible power scheme that permits the use of PPMs with different power and I/O requirements. All of the MB's on-board peripheral I/O (RTC, MHX interface, USB & SD Card) is level-shifted and zero-power-isolated to interface with PPMs at any I/O voltage from +1.65V to +5.5V.

The MB provides the PPM socket with all of the CubeSat Kit Bus Connector I/O and power signals, as well as some dedicated and special-purpose MB signals.[4]

ABSOLUTE MAXIMUM RATINGS

Parameter	Symbol	Value	Units
Operating temperature [5]	T_A	-40 to +85	°C
Voltage on **+5V_USB** bus		-0.3 to +6	V
Voltage on **+5V_SYS** bus			
Voltage on **PWR_MHX** bus			
Voltage on **VCC_SYS** bus			
Voltage on **–FAULT** open-collector output			
Voltage on local **VCC** bus		-0.3 to +5.5	V
Voltage on any I/O pin		-0.3 to (**VCC** + 0.3)	V
Voltage on local **VCC_SD** bus		-0.3 to +3.6	V
Voltage on **VBACKUP** bus		-0.3 to +3.6	V
Voltage at external +5V power connector [6]		-20 to +20	V
DC current through any pin of PPM Connector	$I_{PIN1\ MAX}$	1.2	A
DC current through any pin of CubeSat Kit Bus Connector	$I_{PIN2\ MAX}$	3	A
DC current through external +5V power connector [7]	$I_{EXT\ MAX}$	4	A
DC current through Remove-Before-Flight or Deployment Switches [8]	I_{SW_MAX}	10	A

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[2] The FM430 utilized TI's MSP430 16-bit RISC microcontroller.

[3] The processor was previously referred to in Pumpkin literature as the Flight MCU.

[4] The only signals from the CubeSat Kit Bus Connector that are not presented at the PPM connector are the **S0**–**S5** signals (Remove-Before-Flight and Deployment Switches) and direct MHX interface signals (e.g., **–RTS_MHX**, etc.).

[5] Does not include any SD card fitted to the MB. Typical commercial SD card operating temperatures are 0°C to + 55°C. Typical industrial extended temperature range SD cards operate over -25°C to + 85°C.

[6] Voltages between 0V and +5.5V are passed through to +5V_SYS on the CubeSat Kit Bus.

[7] Limited by a fast-blo 4A fuse.

[8] Make only. Not rated for repetitive make and break cycles of dc current. AC rating for switches alone. Switches are typically wired by the user directly to the MB to simplify S[5..0] bus connections. User should analyze temperature rise on inner layers as a function of currents passed through RBF and Deployment Switches. For high-current applications, wiring directly to the switch (instead of indirectly through the CubeSat Kit Bus connector's S[5..0] pins and the MB PCB) may be preferred.

PHYSICAL CHARACTERISTICS

Parameter	Conditions / Notes	Symbol	Min	Typ	Max	Units
Mass [9]	With standoff and fastener hardware to accept a short PPM (e.g., PPM A1) mounted 9mm above the MB			77		g
	With PPM A1 mounted using abovementioned hardware [10]			88		
	With PPM A1 mounted using abovementioned hardware, 10mm CubeSat Kit Bus Connector extenders and 15.5mm standoffs for MHX transceiver			103		
Height of components above PCB	Without PPM, MHX transceiver or 10mm CubeSat Kit Bus Connector extenders fitted				11.4	mm
	With PPM fitted, and without MHX transceiver or 10mm CubeSat Kit Bus Connector extenders fitted				12.5	
	With MHX transceiver and 10mm CubeSat Kit Bus Connector extender fitted				24.5	
Height of components below PCB					3.5	mm
PCB width	Corner hole pattern matches PC/104			96		mm
PCB length				90		mm
PCB thickness				1.6		mm
Mating external power jack dimensions	Outer diameter				5.5	mm
	Internal diameter		2.1			
CubeSat Kit Bus Connector terminal pitch	Horizontal or vertical distance to nearest terminal			2.54		mm
Switch terminal hole diameter	For C, NO & NC switch terminals [11]			2.54		mm
Compatible coin cell battery dimensions	Diameter			12		mm
	Height		2.0	2.5	2.5	mm

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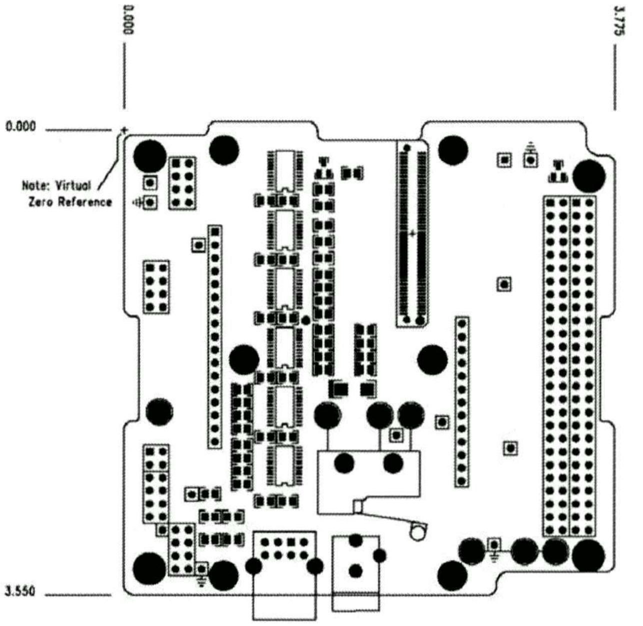
[9] With Remove-Before-Flight Switch and cover fitted. No SD Card in socket.

[10] PPMs are not included with each MB, and must be purchased separately. Data supplied as an example only.

[11] Common, Normally Open and Normally Closed.

SIMPLIFIED MECHANICAL LAYOUT [12]



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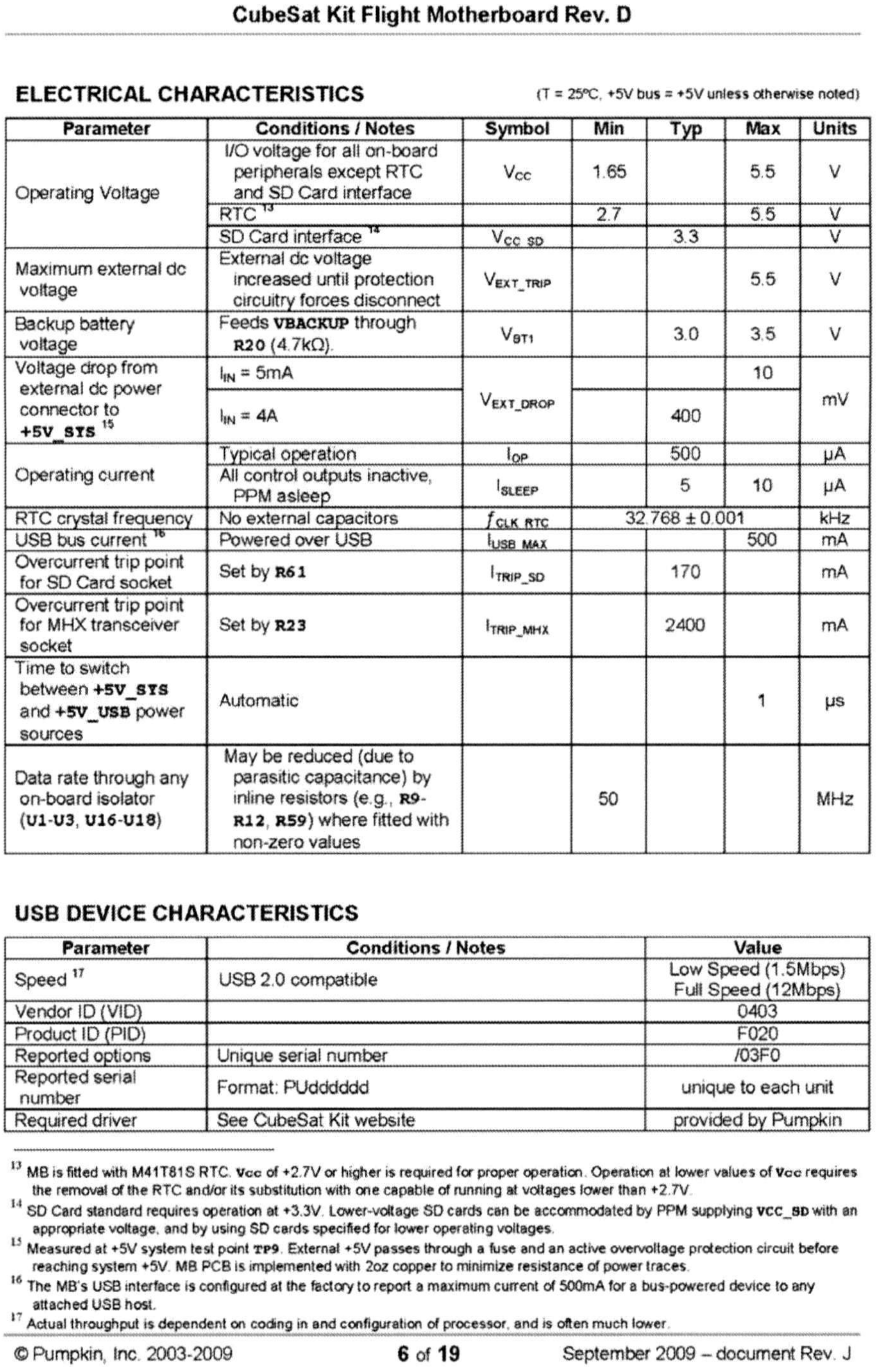
[12] Dimensions in inches.



ELECTRICAL CHARACTERISTICS

(T = 25°C, +5V bus = +5V unless otherwise noted)

Parameter	Conditions / Notes	Symbol	Min	Typ	Max	Units
Operating Voltage	I/O voltage for all on-board peripherals except RTC and SD Card interface	V_{CC}	1.65		5.5	V
	RTC [13]		2.7		5.5	V
	SD Card interface [14]	V_{CC_SD}		3.3		V
Maximum external dc voltage	External dc voltage increased until protection circuitry forces disconnect	V_{EXT_TRIP}			5.5	V
Backup battery voltage	Feeds **VBACKUP** through **R20** (4.7kΩ).	V_{BT1}		3.0	3.5	V
Voltage drop from external dc power connector to **+5V_SYS** [15]	I_{IN} = 5mA	V_{EXT_DROP}			10	mV
	I_{IN} = 4A			400		
Operating current	Typical operation	I_{OP}		500		µA
	All control outputs inactive, PPM asleep	I_{SLEEP}		5	10	µA
RTC crystal frequency	No external capacitors	f_{CLK_RTC}	32.768 ± 0.001			kHz
USB bus current [16]	Powered over USB	I_{USB_MAX}			500	mA
Overcurrent trip point for SD Card socket	Set by **R61**	I_{TRIP_SD}		170		mA
Overcurrent trip point for MHX transceiver socket	Set by **R23**	I_{TRIP_MHX}		2400		mA
Time to switch between **+5V_SYS** and **+5V_USB** power sources	Automatic				1	µs
Data rate through any on-board isolator (**U1-U3**, **U16-U18**)	May be reduced (due to parasitic capacitance) by inline resistors (e.g., **R9-R12**, **R59**) where fitted with non-zero values		50			MHz

USB DEVICE CHARACTERISTICS

Parameter	Conditions / Notes	Value
Speed [17]	USB 2.0 compatible	Low Speed (1.5Mbps) Full Speed (12Mbps)
Vendor ID (VID)		0403
Product ID (PID)		F020
Reported options	Unique serial number	/03F0
Reported serial number	Format: PUdddddd	unique to each unit
Required driver	See CubeSat Kit website	provided by Pumpkin

---

[13] MB is fitted with M41T81S RTC. **Vcc** of +2.7V or higher is required for proper operation. Operation at lower values of **Vcc** requires the removal of the RTC and/or its substitution with one capable of running at voltages lower than +2.7V.

[14] SD Card standard requires operation at +3.3V. Lower-voltage SD cards can be accommodated by PPM supplying **VCC_SD** with an appropriate voltage, and by using SD cards specified for lower operating voltages.

[15] Measured at +5V system test point **TP9**. External +5V passes through a fuse and an active overvoltage protection circuit before reaching system +5V. MB PCB is implemented with 2oz copper to minimize resistance of power traces.

[16] The MB's USB interface is configured at the factory to report a maximum current of 500mA for a bus-powered device to any attached USB host.

[17] Actual throughput is dependent on coding in and configuration of processor, and is often much lower.

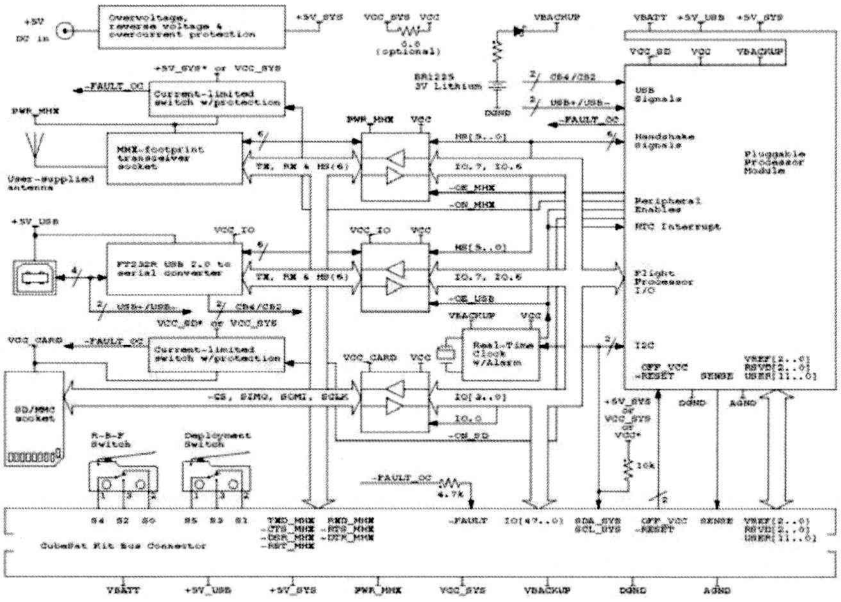
Backup Battery

The MB has a replaceable BR1225 3V Lithium coin cell to serve as a backup battery for real-time clocks and other components requiring battery backup of volatile information.

Battery BT1 is held in place by a coin cell battery holder in one corner of the underside of the MB. The all-metal battery holder is oriented in such a way that once installed onto a CubeSat Kit Base Plate, the battery cannot slide out of its battery holder and is thereby physically restrained along five of six axes. However, since the battery has a conductive outer shell, excessive movement of the battery along its insertion / removal axis could result in a short if it were to contact the Base Plate. Therefore insulating Kapton tape and/or an epoxy or silicone adhesive should be applied to the battery and battery holder.

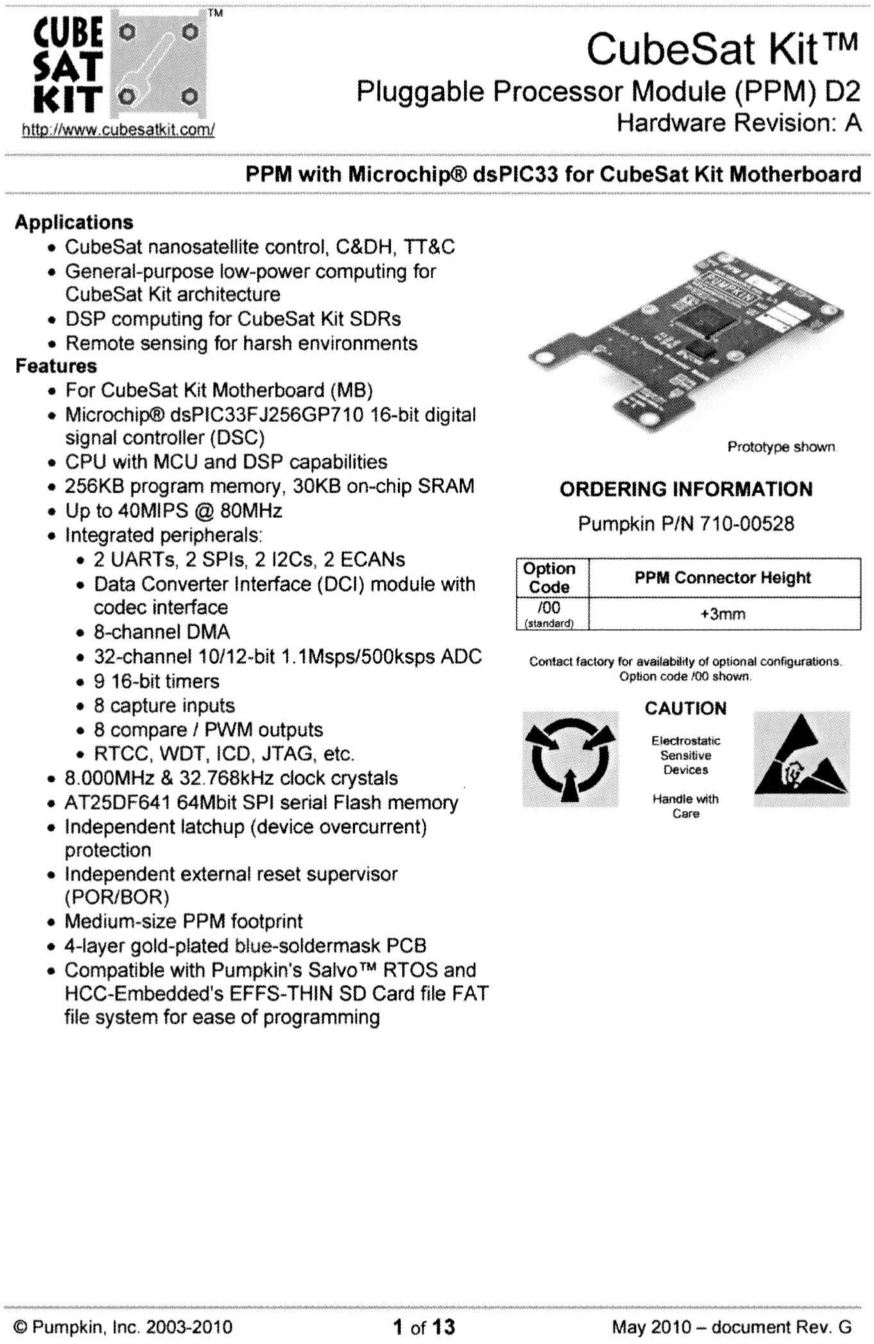
Alternately, the customer can feed **VBACKUP** on the CubeSat Kit bus via their own backup battery located elsewhere in the system.

BLOCK DIAGRAM



*: Default configuration, selectable via 0 Ohm resistors / jumpers.

Acquisition card



http://www.cubesatkit.com/

CubeSat Kit™

Pluggable Processor Module (PPM) D2

Hardware Revision: A

PPM with Microchip® dsPIC33 for CubeSat Kit Motherboard

Applications
- CubeSat nanosatellite control, C&DH, TT&C
- General-purpose low-power computing for CubeSat Kit architecture
- DSP computing for CubeSat Kit SDRs
- Remote sensing for harsh environments

Features
- For CubeSat Kit Motherboard (MB)
- Microchip® dsPIC33FJ256GP710 16-bit digital signal controller (DSC)
- CPU with MCU and DSP capabilities
- 256KB program memory, 30KB on-chip SRAM
- Up to 40MIPS @ 80MHz
- Integrated peripherals:
  - 2 UARTs, 2 SPIs, 2 I2Cs, 2 ECANs
  - Data Converter Interface (DCI) module with codec interface
  - 8-channel DMA
  - 32-channel 10/12-bit 1.1Msps/500ksps ADC
  - 9 16-bit timers
  - 8 capture inputs
  - 8 compare / PWM outputs
  - RTCC, WDT, ICD, JTAG, etc.
- 8.000MHz & 32.768kHz clock crystals
- AT25DF641 64Mbit SPI serial Flash memory
- Independent latchup (device overcurrent) protection
- Independent external reset supervisor (POR/BOR)
- Medium-size PPM footprint
- 4-layer gold-plated blue-soldermask PCB
- Compatible with Pumpkin's Salvo™ RTOS and HCC-Embedded's EFFS-THIN SD Card file FAT file system for ease of programming

Prototype shown

ORDERING INFORMATION

Pumpkin P/N 710-00528

Option Code	PPM Connector Height
/00 (standard)	+3mm

Contact factory for availability of optional configurations. Option code /00 shown.

CAUTION

Electrostatic Sensitive Devices

Handle with Care

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OPERATIONAL DESCRIPTION

PPM D2 enables CubeSat Kit customers to utilize the dsPIC33 processor on a CubeSat Kit Motherboard (MB). PPM D2 uses the 100-pin dsPIC33FJ256GP710-I/PF, with a wide selection of on-chip peripherals. Additionally, a 64Mbit external serial Flash memory is present for off-chip storage.

ABSOLUTE MAXIMUM RATINGS

Parameter	Symbol	Value	Units
Operating temperature	T_A	-40 to +85	°C
Voltage on **+5V_USB** bus		-0.3 to +6.0	V
Voltage on **+5V_SYS** bus			
Voltage on **–FAULT_OC** open-collector output			
Voltage on **VCC** bus		-0.3 to +3.6	V
Voltage on **VCC_SD** bus			
Voltage on any mixed analog/digital processor I/O pin		-0.3 to (**VCC** + 0.3)	V
Voltage on any digital-only processor I/O pin		-0.3 to 6.0	
DC current through any pin of PPM connector **H1**	I_{PIN_MAX}	1.2	A

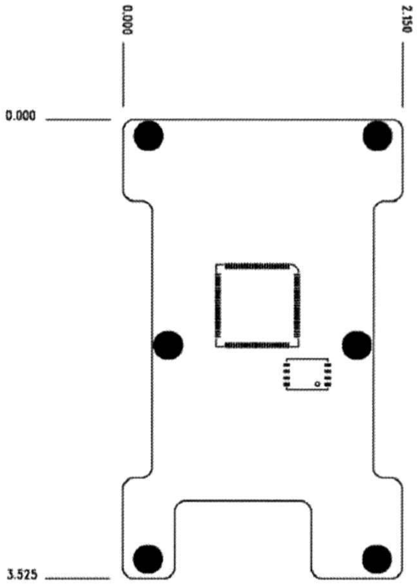
Refer to the dsPIC33FJxxxGPx10 family datasheet for additional absolute maximum ratings associated with processor **U1**, especially per-pin current limits.

PHYSICAL CHARACTERISTICS

Parameter	Conditions / Notes	Symbol	Min	Typ	Max	Units
Mass				17		g
Height of components above PCB					2	mm
Height of components below PCB[1]					4	mm
PCB width	Medium-size PPM			54.6		mm
PCB length				89.5		mm
PCB thickness				1.6		mm

SIMPLIFIED MECHANICAL LAYOUT [2]

PPM D2 is implemented on a medium-size PPM PCB, as shown below.



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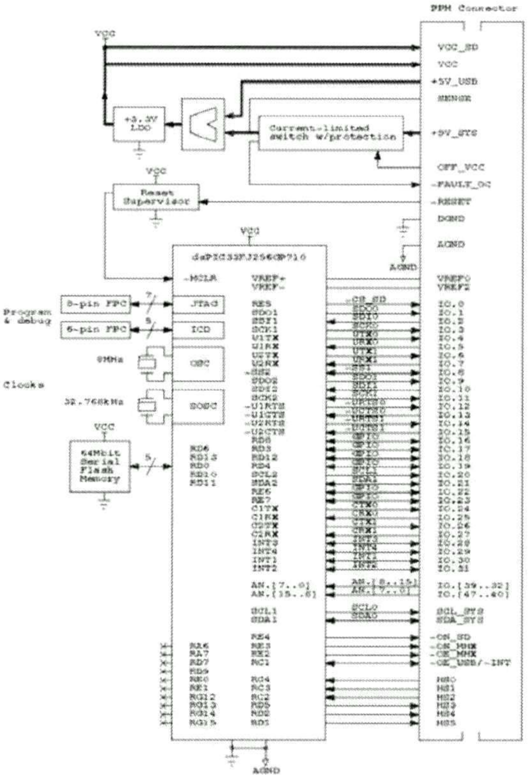
[1] Not including connector H1.

[2] Dimensions in inches.

BLOCK DIAGRAM

PPM D2 provides regulated and current-limited +3.3V power, an external POR/BOR reset supervisor, JTAG and ICD interfaces for programming and debugging, two clock sources, an external high-speed 64Mbit serial Flash memory, connections to all 48 I/O pins of the PPM connector, dedicated MB control and radio handshaking signals, a single-point analog/digital ground, and a careful assignment of the dsPIC33 peripherals to the PPM connector and CubeSat Kit bus. A few of the dsPIC33's 100 pins are not used.

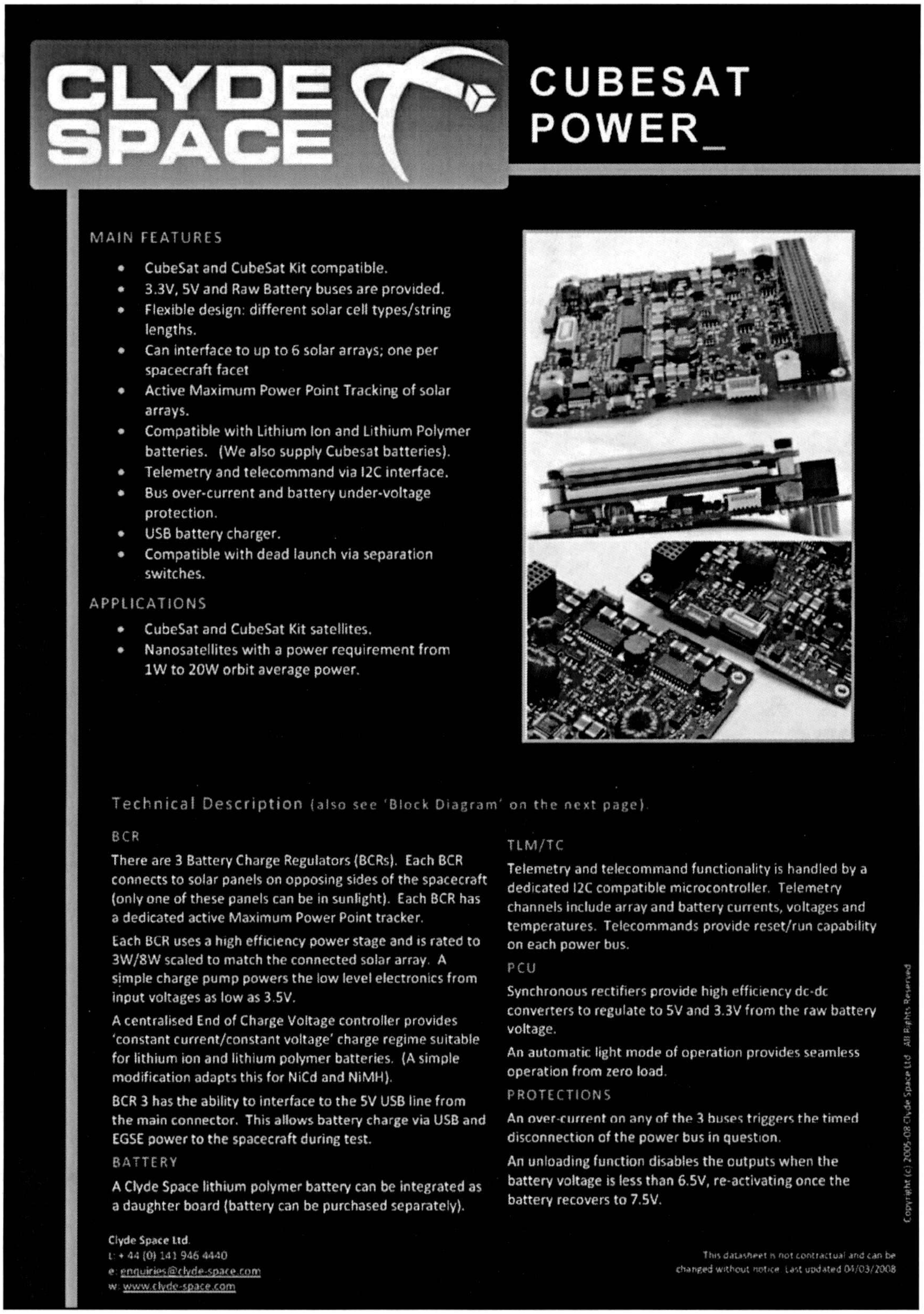


ELECTRICAL CHARACTERISTICS

(T = 25ºC, +5V bus = +5V unless otherwise noted)

Parameter	Conditions / Notes	Symbol	Min	Typ	Max	Units
Reset voltage	**+5V_SYS** reduced until MCU resets	V_{RESET_MAX}			3.1	V
Operating Voltage		V_{CC}		3.3		V
SD Card Voltage		V_{CC_SD}		3.3		V
Operating current	Typical operation	I_{OP}		TBD		mA
	All control outputs inactive, PPM asleep	I_{SLEEP}		TBD	TBD	µA
Primary crystal frequency		f_{CLK_OSC}	8.000 ± 0.01			MHz
Secondary crystal frequency		f_{CLK_SOSC}	32.768 ± 0.001			kHz
Overcurrent trip point for **VCC**	Set by **R3**	I_{TRIP_VCC}		220		mA
Time to switch between **+5V_SYS** and **+5V_USB** power sources	Automatic				1	µs

Electrical Power Systems



CLYDE SPACE

CUBESAT POWER_

MAIN FEATURES

- CubeSat and CubeSat Kit compatible.
- 3.3V, 5V and Raw Battery buses are provided.
- Flexible design: different solar cell types/string lengths.
- Can interface to up to 6 solar arrays; one per spacecraft facet
- Active Maximum Power Point Tracking of solar arrays.
- Compatible with Lithium Ion and Lithium Polymer batteries. (We also supply Cubesat batteries).
- Telemetry and telecommand via I2C interface.
- Bus over-current and battery under-voltage protection.
- USB battery charger.
- Compatible with dead launch via separation switches.

APPLICATIONS

- CubeSat and CubeSat Kit satellites.
- Nanosatellites with a power requirement from 1W to 20W orbit average power.

Technical Description (also see 'Block Diagram' on the next page).

BCR

There are 3 Battery Charge Regulators (BCRs). Each BCR connects to solar panels on opposing sides of the spacecraft (only one of these panels can be in sunlight). Each BCR has a dedicated active Maximum Power Point tracker.

Each BCR uses a high efficiency power stage and is rated to 3W/8W scaled to match the connected solar array. A simple charge pump powers the low level electronics from input voltages as low as 3.5V.

A centralised End of Charge Voltage controller provides 'constant current/constant voltage' charge regime suitable for lithium ion and lithium polymer batteries. (A simple modification adapts this for NiCd and NiMH).

BCR 3 has the ability to interface to the 5V USB line from the main connector. This allows battery charge via USB and EGSE power to the spacecraft during test.

BATTERY

A Clyde Space lithium polymer battery can be integrated as a daughter board (battery can be purchased separately).

TLM/TC

Telemetry and telecommand functionality is handled by a dedicated I2C compatible microcontroller. Telemetry channels include array and battery currents, voltages and temperatures. Telecommands provide reset/run capability on each power bus.

PCU

Synchronous rectifiers provide high efficiency dc-dc converters to regulate to 5V and 3.3V from the raw battery voltage.

An automatic light mode of operation provides seamless operation from zero load.

PROTECTIONS

An over-current on any of the 3 buses triggers the timed disconnection of the power bus in question.

An unloading function disables the outputs when the battery voltage is less than 6.5V, re-activating once the battery recovers to 7.5V.

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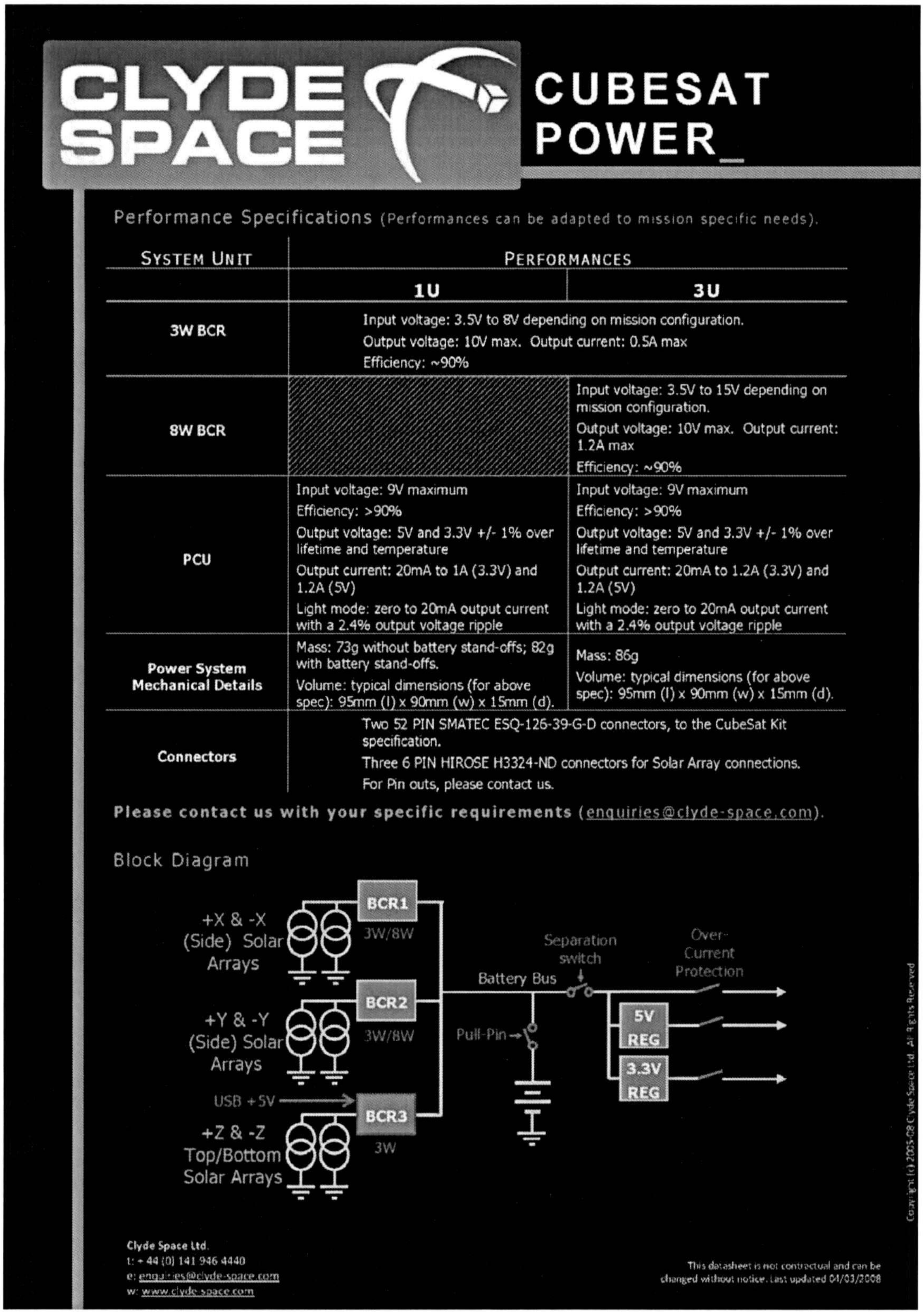

CLYDE SPACE

CUBESAT POWER_

Performance Specifications (Performances can be adapted to mission specific needs).

SYSTEM UNIT	PERFORMANCES	
	1U	**3U**
3W BCR	Input voltage: 3.5V to 8V depending on mission configuration. Output voltage: 10V max. Output current: 0.5A max Efficiency: ~90%	
8W BCR	▨	Input voltage: 3.5V to 15V depending on mission configuration. Output voltage: 10V max. Output current: 1.2A max Efficiency: ~90%
PCU	Input voltage: 9V maximum Efficiency: >90% Output voltage: 5V and 3.3V +/- 1% over lifetime and temperature Output current: 20mA to 1A (3.3V) and 1.2A (5V) Light mode: zero to 20mA output current with a 2.4% output voltage ripple	Input voltage: 9V maximum Efficiency: >90% Output voltage: 5V and 3.3V +/- 1% over lifetime and temperature Output current: 20mA to 1.2A (3.3V) and 1.2A (5V) Light mode: zero to 20mA output current with a 2.4% output voltage ripple
Power System Mechanical Details	Mass: 73g without battery stand-offs; 82g with battery stand-offs. Volume: typical dimensions (for above spec): 95mm (l) x 90mm (w) x 15mm (d).	Mass: 86g Volume: typical dimensions (for above spec): 95mm (l) x 90mm (w) x 15mm (d).
Connectors	Two 52 PIN SMATEC ESQ-126-39-G-D connectors, to the CubeSat Kit specification. Three 6 PIN HIROSE H3324-ND connectors for Solar Array connections. For Pin outs, please contact us.	

Please contact us with your specific requirements (enquiries@clyde-space.com).

Block Diagram

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CLYDE SPACE

SPACE LITHIUM POLYMER BATTERY_

MAIN FEATURES

- High Energy Density, 120Wh/kg to 150Wh/kg
- Suitable for hard vacuum conditions.
- Compatible with operation of 1 Year or more in LEO.
- Integrated battery heater with thermostat to maintain battery temperature above 0°C.
- Battery over-current protection.
- Battery temperature, voltage, and current telemetry.
- Available in 8.2V, 12.3V and 32.8V versions.
- Required battery capacity achieved using parallel connected strings.
- Low magnetic signature due to aluminium foil casing.

APPLICATIONS

- CubeSats and other small satellites.

TECHNICAL DESCRIPTION

A commercial Lithium Polymer cell has been selected by Clyde Space for use with our CubeSat EPS in a space application. Prior to selecting this cell it has undergone a number of tests to verify its performance in a space environment. These tests were as follows:

- Capacity at C/10 under vacuum.
- Radiation up to 500krad.
- DPA
- Capacity at -10°C, 0°C, 20°C and 40°C
- Resistance
- Self Discharge
- Missions Scenario Tests
- EMF vs SOC
- Cycling Tests at reduced pressure (15-20mbars) - 30% DoD, C/2 Charge/Discharge >5000 cycles.

Satisfied with the performance of the cell under these conditions, we are happy to recommend to our customers that they use this cell on their spacecraft.

CELL ACCEPTANCE TESTING

Lot Acceptance tests are performed on flight cells to verify integrity for space use.

Once the batch has passed this test, the cells are matched for capacity and voltage characteristics over temperature. This helps verify the individual cell integrity and also enables selection of cells with matched characteristics for flight batteries.

CONTINUOUS DEVELOPMENT

We are continuing to characterise our cells and are conducting further life tests in order to build up data for battery sizing for different mission scenarios. This will provide confidence in the technology for long duration LEO, GEO and interplanetary missions.

Higher voltage batteries are also being developed with up to 8 cells in series (32.8V) and multiple strings in parallel to achieve the required capacity.

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CLYDE SPACE

SPACE LITHIUM POLYMER BATTERY_

32.8V BATTERY

Our 32.8V battery has a modular design and can easily be adapted to sizes from 1.25Ah up to 10Ah by selecting the appropriate mounting frame. Similar to our CubeSat batteries, the 32.8V battery has integrated functionality and protection, including a thermostatically controlled heater. In addition, the front face PCB provides the further option to have a telemetry and telecommand node on the battery in order to measure and access all battery telemetry information on the spacecraft serial data-bus.

1U CUBESAT BATTERY

The 1U Battery integrates with our power system and is scalable to increase the total capacity. Each battery has an integrated battery heater with thermostat, battery cell voltage, terminal voltage, as well as current and temperature monitoring.

The bottom picture on the previous page shows a prototype of the battery board design with two lithium polymer cells. The cells are coated in Kapton® for insulation, although the foil bag is not connected to battery negative or positive. The cells are held onto the PCB using thermally conductive adhesive. The capacity of each battery is 1.25Ah at a maximum voltage of 8.2V.

The figure middle right shows the battery and EPS fully integrated with 2 lithium polymer batteries in parallel, providing approximately 20Whrs of capacity.

With one battery integrated onto the EPS, the total height of the unit is 14mm from the EPS board surface; with two batteries this is 21mm. The mass of the EPS is 80g and the mass of one, two cell, 10Whr battery is 62g.

3U CUBESAT BATTERY

The 3U battery has a main battery board with two series cells which are mounted flat, side-by-side on a PC104 sized, CubeSat kit compatible PCB. Two additional, two cell battery daughter boards can then be integrated with this main PCB to increase the capacity (in the same way that the daughter boards integrate with the 1U EPS). The main battery board has its own I2C microcontroller for telemetry and telecommand. It can also provide a further two voltages as an option: 12V at 300mA and 50V at 1mA. These voltages are accessed via spare pins on the main header connector.

This configuration results in a 2s3p battery (2 series cells per string and 6 strings in parallel). The capacity of each 2s3p is 3.75Ah at a maximum voltage of 8.2V. The main battery PCB (PC104) weighs approximately 80g and each daughter battery unit weighs 62g.

32.8V 5Ah Battery for Small Satellites

CubeSat Power board with integrated 20Whr battery

12.3V 15Whr Battery Cell String for Nanosatellites.

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CLYDE SPACE

SMALL SATELLITE SOLAR PANELS_

MAIN FEATURES

- High efficiency solar arrays for satellite classes from PICOSatellites and CubeSats to Minisatellites.
- Our assembly procedures are compatible with a range of solar cell types from a range of manufacturers.
  - Providing fast, quality, custom solutions based on cell availability and cost. (We have delivered two 24W solar arrays in 5 weeks from order).
- Clyde Space has developed a low-cost assembly method based on traditional techniques using heritage, space-qualified materials.
- Clyde Space has experience in the use of various solar panel substrates including carbon fibre composite panels, aluminium and PCB based.
- Our PCB substrates can incorporate magnetorquers coils and other sensors.

APPLICATIONS

- CubeSats, CubeSats with deployed arrays and other small satellites.

Technical Description For more info see www.clyde-space.com.

Clyde Space solar array design and manufacturing techniques have been developed based on traditional solar array assembly techniques, but adapted to reduce assembly costs in order to meet the tighter budget needs of the small satellite community.

MANUFACTURING CAPABILITY

The Clyde Space capability extends to solar panels of approximately 500mm x 500mm, a size that is more typically a test coupon for traditional solar array manufacturers.

Our laydown technique allows us to use a variety of cell sizes and types without the need to modify our assembly equipment and jigs. This enables us to reduce costs and to react quickly to cell availability for customers with tight schedules.

Our extensive industry contacts enable us to source affordable cells, quickly and with impressive performance characteristics.

POWER SYSTEM AND MISSION DESIGN EXPERIENCE

Unlike most solar panel manufacturers, Clyde Space also produces high performance small satellite electrical power systems and batteries. In addition, our have extensive experience in the design of space missions, this enables us to understand customer requirements and to advise on solar array configuration to achieve optimum power levels.

Continuous Development

Clyde Space operates a system of continuous development. We assess our procedures and suppliers to determine whether we can reduce costs whilst at the same time maintaining quality. For example, our development of PCB substrate techniques eliminates solar panel wiring and bus-baring at the end of columns; saving significant assembly time.

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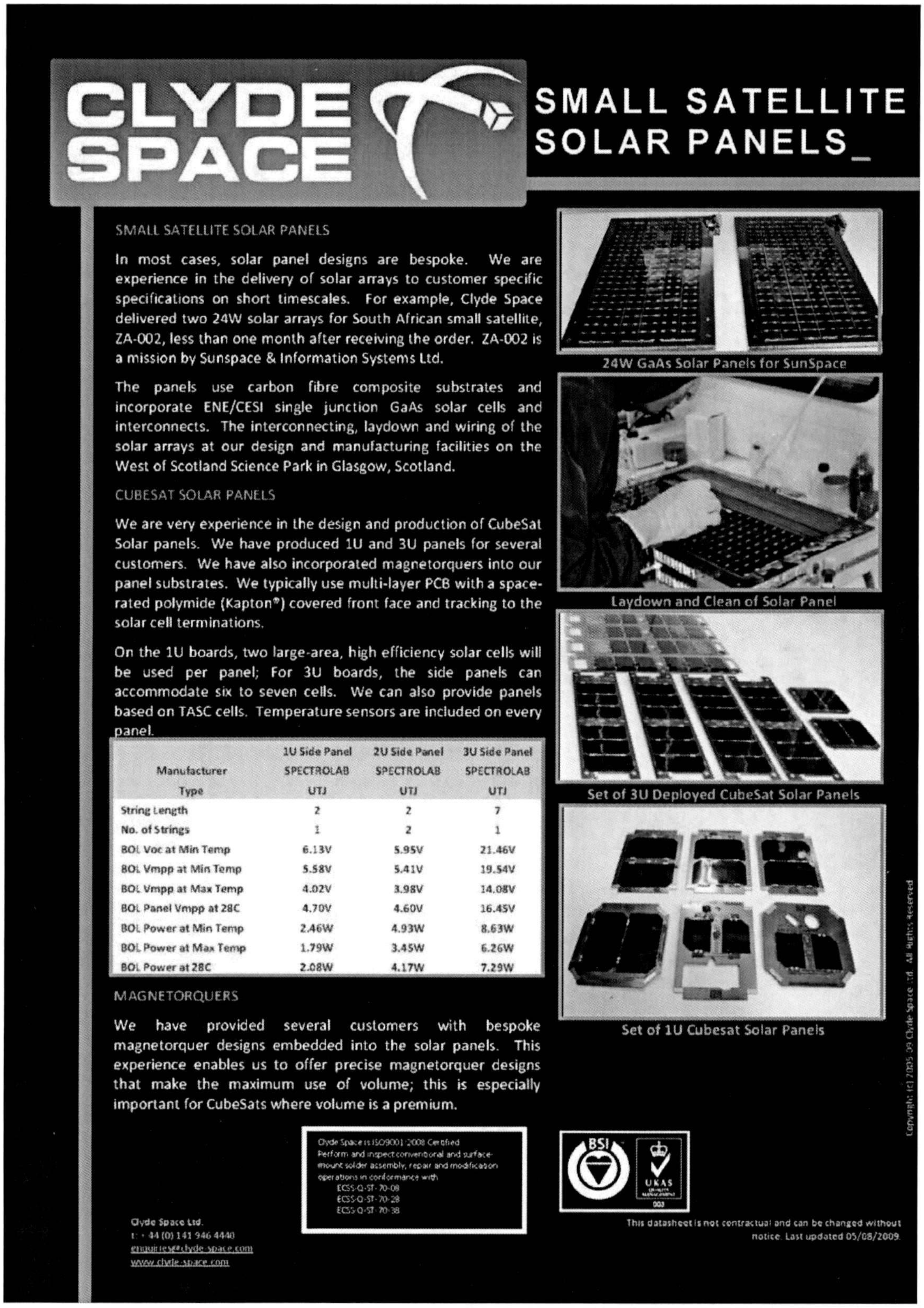


SMALL SATELLITE SOLAR PANELS_

SMALL SATELLITE SOLAR PANELS

In most cases, solar panel designs are bespoke. We are experience in the delivery of solar arrays to customer specific specifications on short timescales. For example, Clyde Space delivered two 24W solar arrays for South African small satellite, ZA-002, less than one month after receiving the order. ZA-002 is a mission by Sunspace & Information Systems Ltd.

The panels use carbon fibre composite substrates and incorporate ENE/CESI single junction GaAs solar cells and interconnects. The interconnecting, laydown and wiring of the solar arrays at our design and manufacturing facilities on the West of Scotland Science Park in Glasgow, Scotland.

CUBESAT SOLAR PANELS

We are very experience in the design and production of CubeSat Solar panels. We have produced 1U and 3U panels for several customers. We have also incorporated magnetorquers into our panel substrates. We typically use multi-layer PCB with a space-rated polymide (Kapton®) covered front face and tracking to the solar cell terminations.

On the 1U boards, two large-area, high efficiency solar cells will be used per panel; For 3U boards, the side panels can accommodate six to seven cells. We can also provide panels based on TASC cells. Temperature sensors are included on every panel.

	1U Side Panel	2U Side Panel	3U Side Panel
Manufacturer	SPECTROLAB	SPECTROLAB	SPECTROLAB
Type	UTJ	UTJ	UTJ
String Length	2	2	7
No. of Strings	1	2	1
BOL Voc at Min Temp	6.13V	5.95V	21.46V
BOL Vmpp at Min Temp	5.58V	5.41V	19.54V
BOL Vmpp at Max Temp	4.02V	3.98V	14.08V
BOL Panel Vmpp at 28C	4.70V	4.60V	16.45V
BOL Power at Min Temp	2.46W	4.93W	8.63W
BOL Power at Max Temp	1.79W	3.45W	6.26W
BOL Power at 28C	2.08W	4.17W	7.29W

MAGNETORQUERS

We have provided several customers with bespoke magnetorquer designs embedded into the solar panels. This experience enables us to offer precise magnetorquer designs that make the maximum use of volume; this is especially important for CubeSats where volume is a premium.

24W GaAs Solar Panels for SunSpace

Laydown and Clean of Solar Panel

Set of 3U Deployed CubeSat Solar Panels

Set of 1U Cubesat Solar Panels

Clyde Space is ISO9001:2008 Certified
Perform and inspect conventional and surface-mount solder assembly, repair and modification operations in conformance with
ECSS-Q-ST-70-08
ECSS-Q-ST-70-28
ECSS-Q-ST-70-38

Clyde Space Ltd.
t: +44 (0) 141 946 4440
enquiries@clyde-space.com
www.clyde-space.com

GPS

SUPERSTAR II

Features

- Carrier phase tracking
- Binary or NMEA interface
- Standard support for SBAS (WAAS, EGNOS) corrections

Benefits

- Improved positioning accuracy and reliability
- Suitable for all systems, whether the focus is high throughput or exceptional compatibility
- Increased accuracy without extra cost or additional equipment

NovAtel's SUPERSTAR II™ is designed for applications requiring highly reliable positioning performance with low power consumption and cost.

Carrier phase capability and SBAS support

The SUPERSTAR II features 12-channel code and carrier phase tracking for increased accuracy. Position, velocity, time (PVT) and raw carrier phase measurements output are available at rates of up to 5 Hertz.

The SUPERSTAR II also takes advantage of the corrections offered by SBAS systems such as WAAS and EGNOS for improved accuracy. For precise timing applications, the SUPERSTAR II features a 1PPS accuracy of 50 nanoseconds (typical).

Small package and low power consumption

The SUPERSTAR II, designed as a drop-in replacement for the SUPERSTAR I, fits with ease into even the smallest systems, measuring just 46 millimeters by 71 millimeters. Available in 3.3 Volt or 5 Volt versions, the receiver also features the low power consumption of 0.5 Watts or 0.8 Watts, respectively.

Flexible interface

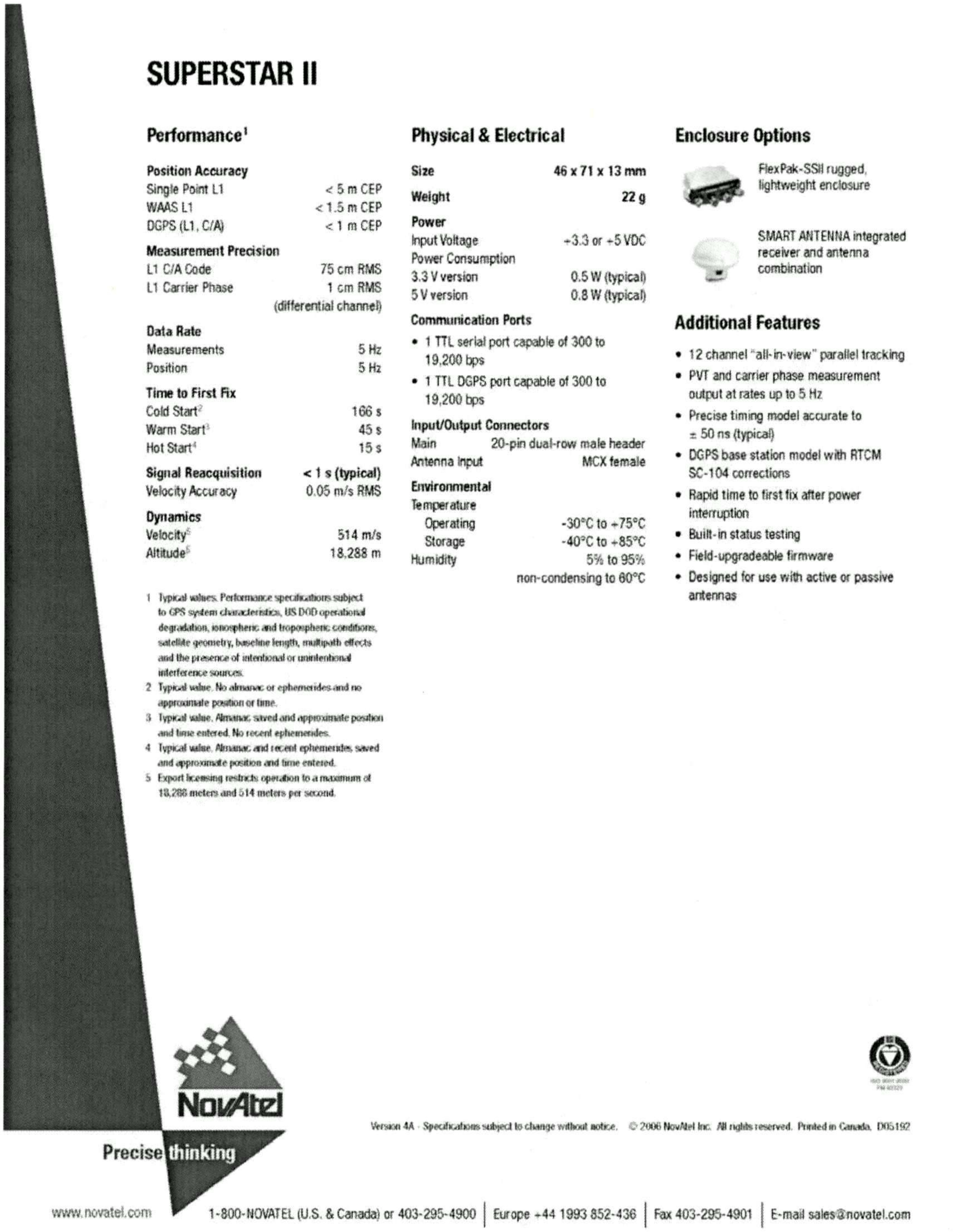
The SUPERSTAR II offers a flexible command and log interface. System integrators can choose either NovAtel's proprietary L1 family binary format, which allows for high throughput, or the industry-standard NMEA format, to ensure compatibility. For DGPS applications, the SUPERSTAR II features RTCM SC-104 messages.

Development kit available

To further support system design and integration efforts, the SUPERSTAR II development kit is available with the SUPERSTAR II in the FlexPak enclosure, a magnetic mount antenna with RF cable, a serial cable, an automotive adapter, and an AC adapter. NovAtel's Windows®-based StarView™ software is also provided, with an easy to use interface for receiver communication and configuration.

NovAtel

Precise thinking



SUPERSTAR II

Performance[1]

Position Accuracy	
Single Point L1	< 5 m CEP
WAAS L1	< 1.5 m CEP
DGPS (L1, C/A)	< 1 m CEP
Measurement Precision	
L1 C/A Code	75 cm RMS
L1 Carrier Phase	1 cm RMS (differential channel)
Data Rate	
Measurements	5 Hz
Position	5 Hz
Time to First Fix	
Cold Start[2]	166 s
Warm Start[3]	45 s
Hot Start[4]	15 s
Signal Reacquisition	**< 1 s (typical)**
Velocity Accuracy	0.05 m/s RMS
Dynamics	
Velocity[5]	514 m/s
Altitude[5]	18,288 m

[1] Typical values. Performance specifications subject to GPS system characteristics, US DOD operational degradation, ionospheric and tropospheric conditions, satellite geometry, baseline length, multipath effects and the presence of intentional or unintentional interference sources.

[2] Typical value. No almanac or ephemerides and no approximate position or time.

[3] Typical value. Almanac saved and approximate position and time entered. No recent ephemerides.

[4] Typical value. Almanac and recent ephemerides saved and approximate position and time entered.

[5] Export licensing restricts operation to a maximum of 18,288 meters and 514 meters per second.

Physical & Electrical

Size	**46 x 71 x 13 mm**
Weight	**22 g**
Power	
Input Voltage	+3.3 or +5 VDC
Power Consumption	
3.3 V version	0.5 W (typical)
5 V version	0.8 W (typical)

Communication Ports

- 1 TTL serial port capable of 300 to 19,200 bps
- 1 TTL DGPS port capable of 300 to 19,200 bps

Input/Output Connectors	
Main	20-pin dual-row male header
Antenna Input	MCX female
Environmental	
Temperature	
Operating	-30°C to +75°C
Storage	-40°C to +85°C
Humidity	5% to 95% non-condensing to 60°C

Enclosure Options

FlexPak-SSII rugged, lightweight enclosure

SMART ANTENNA integrated receiver and antenna combination

Additional Features

- 12 channel "all-in-view" parallel tracking
- PVT and carrier phase measurement output at rates up to 5 Hz
- Precise timing model accurate to ± 50 ns (typical)
- DGPS base station model with RTCM SC-104 corrections
- Rapid time to first fix after power interruption
- Built-in status testing
- Field-upgradeable firmware
- Designed for use with active or passive antennas

NovAtel

Precise thinking

www.novatel.com 1-800-NOVATEL (U.S. & Canada) or 403-295-4900 | Europe +44 1993 852-436 | Fax 403-295-4901 | E-mail sales@novatel.com

Acoustic trigger (optional)

AKUSTICA

Chips That Can Hear, Speak, and Sense the World Around Them

PRODUCT BRIEF >

AKU2002C

CMOS MEMS Digital Microphone

GENERAL DESCRIPTION

BENEFITS OF THE AKU2002C

FUNCTIONAL BLOCK DIAGRAM

Key Features

- High performance, omni-directional digital-output microphone
- Monolithic CMOS MEMS microphone chip
- 3.76mm x 4.72mm x 1.75mm package size
- Industry standard digital microphone output compatible with CODECs for many applications
- 1.8V – 3.6V operating voltage
- 56 dB SNR
- Better than -55dB power supply rejection (PSR)
- Ultra-low power sleep mode
- Supports clock frequencies from 1-4MHz

Applications

- Mobile computers designed to support high quality voice applications and where a high degree of EM/RF immunity is required
- Microphone Arrays utilizing noise cancellation and beam steering applications
- Other small, thin consumer electronic devices using more than one microphone

Akustica, Inc.
2835 East Carson Street, Suite 301
Pittsburgh, PA 15203 USA
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www.akustica.com
sales: sales@akustica.com

AKUSTICA

Camera

UI-1645LE-C □USB2.0 Color CMOS SXGA□1.3 Megapixel Camera □CS-Mount Housing Model

Specifications

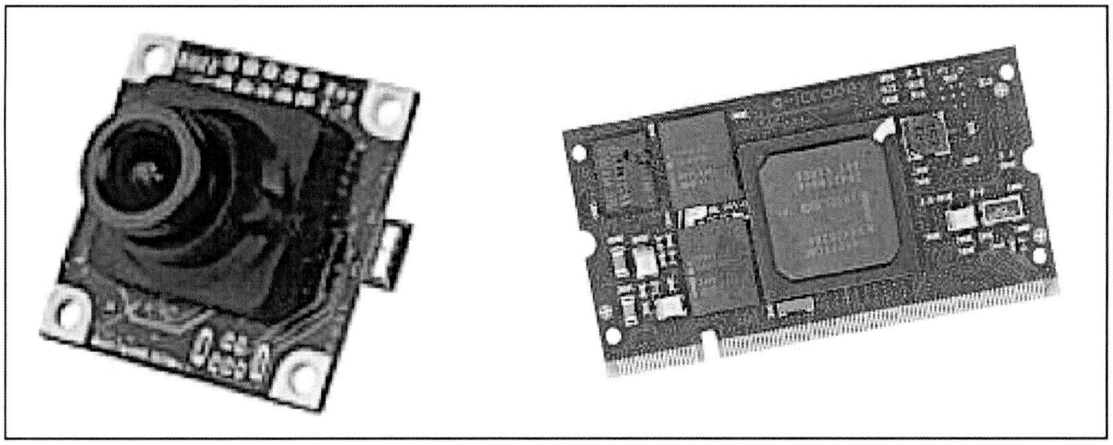
Type	UI-1645LE-C
Image Sensor	1/3" CMOS
Resolution	1280 (H) x 1024(V) pixel, SXGA/1.3

	MP
Shutter	Rolling
max. fps in Freerun mode at full resolution	26 fps
Exposure Time in Freerun mode	37µs - 10 s
AOI modes	H2 + V2
AOI with 320 x 240 Pixels (CIF)	270 fps
Subsampling Modes	H2 + V2
Subsampling Factors	x2, x4
Resolution, fps	640 x 512, 87 fps
	320 x 256, 270 fps
Gain Modes	RGB + Master
I / O s	LE models xxx6, xxx7, xxx8: trigger in, flash out, 2 digital outs
	(TTL compatible) / optional (on request)
Sensor Model	MT9M131
Pixel Clock	5 - 40 MHz
Pixel Pitch in µm	3,6
Optical Size	4,61 x 3,69 mm
Aspect Ratio	5:4
Exact Real Diagonal	5,9 mm
Exact Real Diagonal	1/2,7"
Regulations	CE class A, CE class B, FCC (depending on model)

Dimension	44 x 44 x 25,4 mm (W x H x D)

Video and data compression card

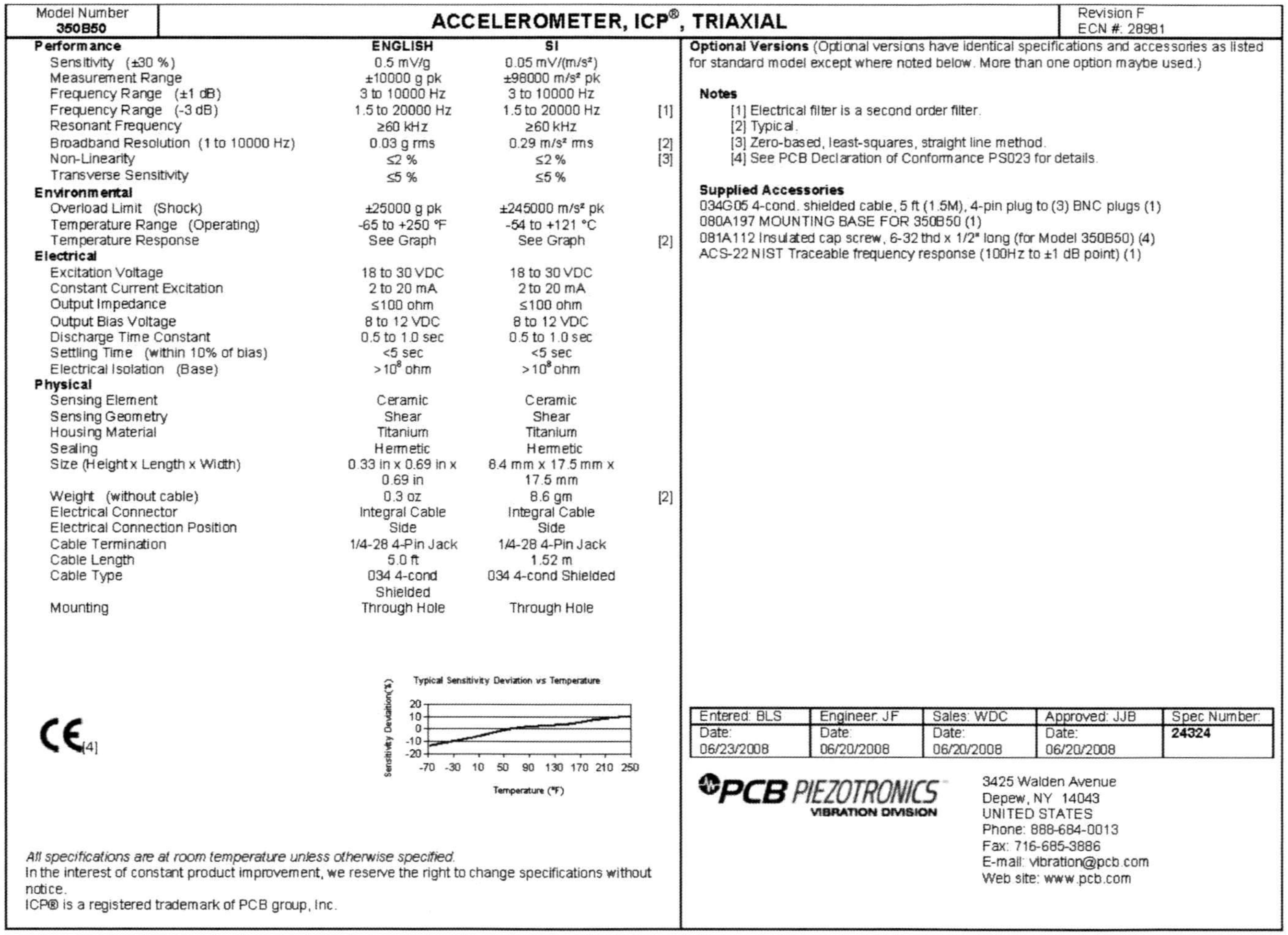
Payload developed and demonstrated within the M-cubed Cubesat: The primary payload of M3 is an IDS UI-1646LE-C 1.3 MegaPixel CMOS color camera with a 9.6 mm EFL (Effective Focal Length) Plano-convex lens . The camera will take an image and save it to a Colibri PXA270 microprocessor at a resolution of 1280 x 1024 pixels, each pixel with a size of 3.6 μm x 3.6 μm. This allows for moderate to high-resolution images of the Earth after postprocessing. Even with the lens positioned at the correct focal length, the whole camera payload subsystem is fairly small and takes up only 55 cm3 of volume. The CMOS camera is also referred to as μEye.



Reference paper: Dmitriy L. Bekker et al., "*A CubeSat Design to Validate the Virtex-5 FPGA for Spaceborne Image Processing*", Aerospace Conference, 2010 IEEE

25kHz wired accelerometer

PCB Model 350B50



Model Number
350B50

ACCELEROMETER, ICP®, TRIAXIAL

Revision F
ECN #: 28981

Performance	**ENGLISH**	**SI**	
Sensitivity (±30 %)	0.5 mV/g	0.05 mV/(m/s²)	
Measurement Range	±10000 g pk	±98000 m/s² pk	
Frequency Range (±1 dB)	3 to 10000 Hz	3 to 10000 Hz	
Frequency Range (-3 dB)	1.5 to 20000 Hz	1.5 to 20000 Hz	[1]
Resonant Frequency	≥60 kHz	≥60 kHz	
Broadband Resolution (1 to 10000 Hz)	0.03 g rms	0.29 m/s² rms	[2]
Non-Linearity	≤2 %	≤2 %	[3]
Transverse Sensitivity	≤5 %	≤5 %	
Environmental			
Overload Limit (Shock)	±25000 g pk	±245000 m/s² pk	
Temperature Range (Operating)	-65 to +250 °F	-54 to +121 °C	
Temperature Response	See Graph	See Graph	[2]
Electrical			
Excitation Voltage	18 to 30 VDC	18 to 30 VDC	
Constant Current Excitation	2 to 20 mA	2 to 20 mA	
Output Impedance	≤100 ohm	≤100 ohm	
Output Bias Voltage	8 to 12 VDC	8 to 12 VDC	
Discharge Time Constant	0.5 to 1.0 sec	0.5 to 1.0 sec	
Settling Time (within 10% of bias)	<5 sec	<5 sec	
Electrical Isolation (Base)	>10^8 ohm	>10^8 ohm	
Physical			
Sensing Element	Ceramic	Ceramic	
Sensing Geometry	Shear	Shear	
Housing Material	Titanium	Titanium	
Sealing	Hermetic	Hermetic	
Size (Height x Length x Width)	0.33 in x 0.69 in x 0.69 in	8.4 mm x 17.5 mm x 17.5 mm	
Weight (without cable)	0.3 oz	8.6 gm	[2]
Electrical Connector	Integral Cable	Integral Cable	
Electrical Connection Position	Side	Side	
Cable Termination	1/4-28 4-Pin Jack	1/4-28 4-Pin Jack	
Cable Length	5.0 ft	1.52 m	
Cable Type	034 4-cond Shielded	034 4-cond Shielded	
Mounting	Through Hole	Through Hole	

CE[4]

All specifications are at room temperature unless otherwise specified.
In the interest of constant product improvement, we reserve the right to change specifications without notice.
ICP® is a registered trademark of PCB group, Inc.

Optional Versions (Optional versions have identical specifications and accessories as listed for standard model except where noted below. More than one option maybe used.)

Notes

[1] Electrical filter is a second order filter.
[2] Typical.
[3] Zero-based, least-squares, straight line method.
[4] See PCB Declaration of Conformance PS023 for details.

Supplied Accessories

034G05 4-cond. shielded cable, 5 ft (1.5M), 4-pin plug to (3) BNC plugs (1)
080A197 MOUNTING BASE FOR 350B50 (1)
081A112 Insulated cap screw, 6-32 thd x 1/2" long (for Model 350B50) (4)
ACS-22 NIST Traceable frequency response (100Hz to ±1 dB point) (1)

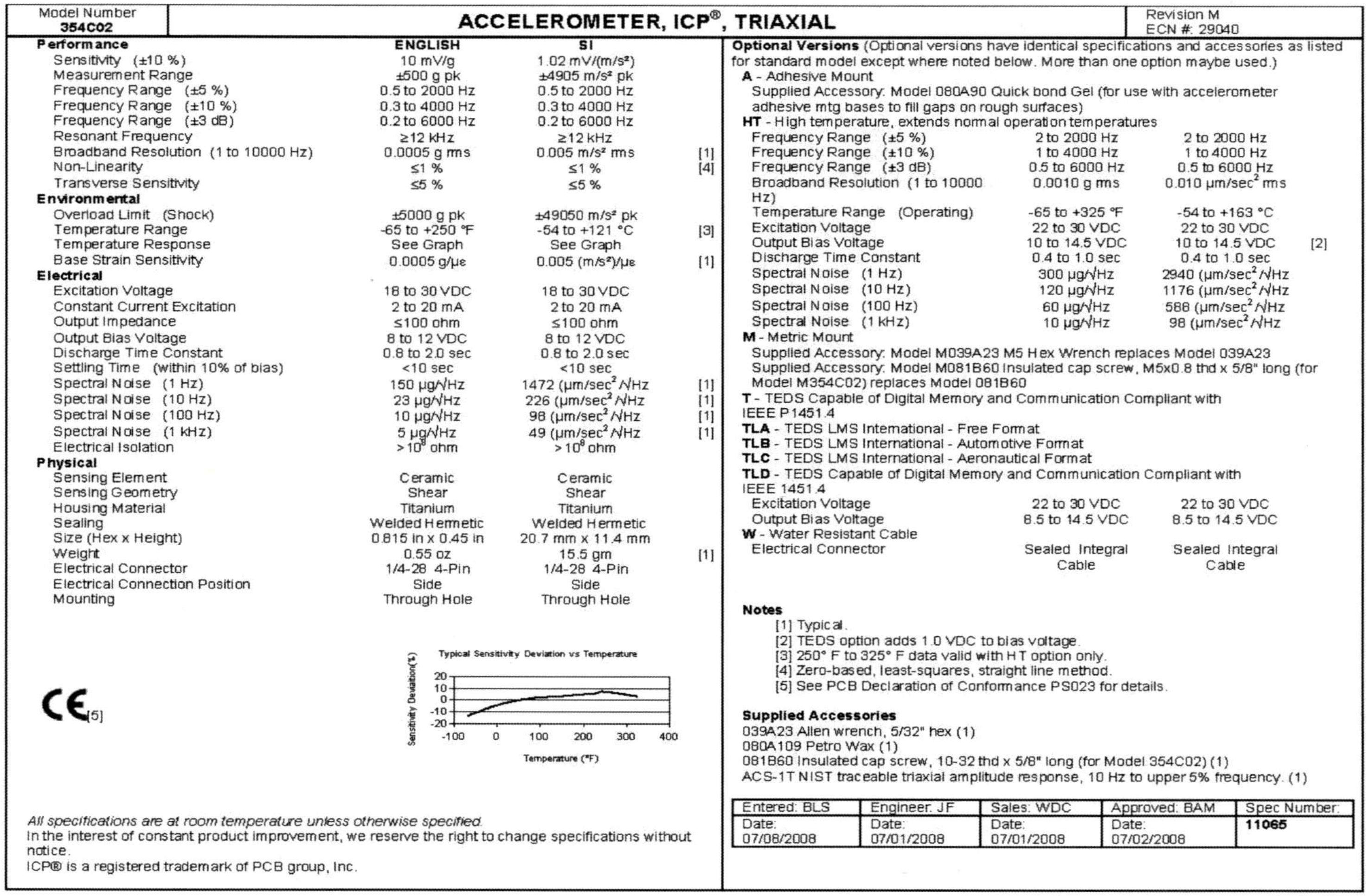
Entered: BLS	Engineer: JF	Sales: WDC	Approved: JJB	Spec Number:
Date: 06/23/2008	Date: 06/20/2008	Date: 06/20/2008	Date: 06/20/2008	**24324**

PCB PIEZOTRONICS
VIBRATION DIVISION

3425 Walden Avenue
Depew, NY 14043
UNITED STATES
Phone: 888-684-0013
Fax: 716-685-3886
E-mail: vibration@pcb.com
Web site: www.pcb.com

4kHz wired accelerometer

PCB Model 350B50



Model Number **354C02**	**ACCELEROMETER, ICP®, TRIAXIAL**	Revision M ECN #: 29040

Performance	**ENGLISH**	**SI**	
Sensitivity (±10 %)	10 mV/g	1.02 mV/(m/s^2)	
Measurement Range	±500 g pk	±4905 m/s^2 pk	
Frequency Range (±5 %)	0.5 to 2000 Hz	0.5 to 2000 Hz	
Frequency Range (±10 %)	0.3 to 4000 Hz	0.3 to 4000 Hz	
Frequency Range (±3 dB)	0.2 to 6000 Hz	0.2 to 6000 Hz	
Resonant Frequency	≥12 kHz	≥12 kHz	
Broadband Resolution (1 to 10000 Hz)	0.0005 g rms	0.005 m/s^2 rms	[1]
Non-Linearity	≤1 %	≤1 %	[4]
Transverse Sensitivity	≤5 %	≤5 %	
Environmental			
Overload Limit (Shock)	±5000 g pk	±49050 m/s^2 pk	
Temperature Range	-65 to +250 °F	-54 to +121 °C	[3]
Temperature Response	See Graph	See Graph	
Base Strain Sensitivity	0.0005 g/µε	0.005 (m/s^2)/µε	[1]
Electrical			
Excitation Voltage	18 to 30 VDC	18 to 30 VDC	
Constant Current Excitation	2 to 20 mA	2 to 20 mA	
Output Impedance	≤100 ohm	≤100 ohm	
Output Bias Voltage	8 to 12 VDC	8 to 12 VDC	
Discharge Time Constant	0.8 to 2.0 sec	0.8 to 2.0 sec	
Settling Time (within 10% of bias)	<10 sec	<10 sec	
Spectral Noise (1 Hz)	150 µg/√Hz	1472 (µm/sec^2 /√Hz	[1]
Spectral Noise (10 Hz)	23 µg/√Hz	226 (µm/sec^2 /√Hz	[1]
Spectral Noise (100 Hz)	10 µg/√Hz	98 (µm/sec^2 /√Hz	[1]
Spectral Noise (1 kHz)	5 µg/√Hz	49 (µm/sec^2 /√Hz	[1]
Electrical Isolation	>10^8 ohm	>10^8 ohm	
Physical			
Sensing Element	Ceramic	Ceramic	
Sensing Geometry	Shear	Shear	
Housing Material	Titanium	Titanium	
Sealing	Welded Hermetic	Welded Hermetic	
Size (Hex x Height)	0.815 in x 0.45 in	20.7 mm x 11.4 mm	
Weight	0.55 oz	15.5 gm	[1]
Electrical Connector	1/4-28 4-Pin	1/4-28 4-Pin	
Electrical Connection Position	Side	Side	
Mounting	Through Hole	Through Hole	

All specifications are at room temperature unless otherwise specified.
In the interest of constant product improvement, we reserve the right to change specifications without notice.
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Optional Versions (Optional versions have identical specifications and accessories as listed for standard model except where noted below. More than one option maybe used.)

A - Adhesive Mount
Supplied Accessory: Model 080A90 Quick bond Gel (for use with accelerometer adhesive mtg bases to fill gaps on rough surfaces)

HT - High temperature, extends normal operation temperatures

Frequency Range (±5 %)	2 to 2000 Hz	2 to 2000 Hz	
Frequency Range (±10 %)	1 to 4000 Hz	1 to 4000 Hz	
Frequency Range (±3 dB)	0.5 to 6000 Hz	0.5 to 6000 Hz	
Broadband Resolution (1 to 10000 Hz)	0.0010 g rms	0.010 µm/sec^2 rms	
Temperature Range (Operating)	-65 to +325 °F	-54 to +163 °C	
Excitation Voltage	22 to 30 VDC	22 to 30 VDC	
Output Bias Voltage	10 to 14.5 VDC	10 to 14.5 VDC	[2]
Discharge Time Constant	0.4 to 1.0 sec	0.4 to 1.0 sec	
Spectral Noise (1 Hz)	300 µg/√Hz	2940 (µm/sec^2 /√Hz	
Spectral Noise (10 Hz)	120 µg/√Hz	1176 (µm/sec^2 /√Hz	
Spectral Noise (100 Hz)	60 µg/√Hz	588 (µm/sec^2 /√Hz	
Spectral Noise (1 kHz)	10 µg/√Hz	98 (µm/sec^2 /√Hz	

M - Metric Mount
Supplied Accessory: Model M039A23 M5 Hex Wrench replaces Model 039A23
Supplied Accessory: Model M081B60 Insulated cap screw, M5x0.8 thd x 5/8" long (for Model M354C02) replaces Model 081B60

T - TEDS Capable of Digital Memory and Communication Compliant with IEEE P1451.4

TLA - TEDS LMS International - Free Format

TLB - TEDS LMS International - Automotive Format

TLC - TEDS LMS International - Aeronautical Format

TLD - TEDS Capable of Digital Memory and Communication Compliant with IEEE 1451.4

Excitation Voltage	22 to 30 VDC	22 to 30 VDC
Output Bias Voltage	8.5 to 14.5 VDC	8.5 to 14.5 VDC

W - Water Resistant Cable

Electrical Connector	Sealed Integral Cable	Sealed Integral Cable

Notes

[1] Typical.
[2] TEDS option adds 1.0 VDC to bias voltage.
[3] 250° F to 325° F data valid with HT option only.
[4] Zero-based, least-squares, straight line method.
[5] See PCB Declaration of Conformance PS023 for details.

Supplied Accessories

039A23 Allen wrench, 5/32" hex (1)
080A109 Petro Wax (1)
081B60 Insulated cap screw, 10-32 thd x 5/8" long (for Model 354C02) (1)
ACS-1T NIST traceable triaxial amplitude response, 10 Hz to upper 5% frequency. (1)

Entered: BLS	Engineer: JF	Sales: WDC	Approved: BAM	Spec Number:
Date: 07/08/2008	Date: 07/01/2008	Date: 07/01/2008	Date: 07/02/2008	**11065**

4kHz Wireless Accelerometer and Receiver

Technical Product Overview

G-Link®

2.4 GHz Wireless Accelerometer Node

Introduction

Combining MEMS accelerometers with MicroStrain's award-winning Micro Datalogging Transceiver systems, G-Link® is a high speed, triaxial accelerometer node, designed to operate as part of an integrated wireless sensor network system.

Featuring 2 KHz sweep rates, combined with 2 Mbytes of flash memory, these little nodes pack a lot of power in a small package. Every node in the wireless network is assigned a unique 16 bit address, so a single host transceiver can address thousands of multichannel sensor nodes.

The bi-directional RF communications link can trigger a sample to be logged from 70 meters, or request real-time data to be transmitted to the host PC for data acquisition/analysis. The frequency agile system enables simultaneous real-time streaming from up to 16 nodes in the 2.4 GHz range.

Available in 2*g* or 10*g* range, these small, fast, wireless accelerometers can be used to monitor tilt and vibration in a wide range of machines and structures.

A Software Development Kit is available, which includes fully-commented source code and a compiled executable for: Microsoft® C++ 6.0, Microsoft® Visual Studio C++ .NET 7.1, Microsoft® VB 6.0, Microsoft® VB.NET 2003, Microsoft® VB.NET 2005 and LabVIEW® 7.1.

Features & Benefits

- 2.4 GHz direct sequence spread spectrum radio is license free worldwide
- IEEE 802.15.4 open communication architecture
- supports simultaneous streaming from multiple nodes to PC
- Available with 2*g* or 10*g* range
- datalogging rates up to 2048 Hz
- real-time streaming rates up to 736 Hz
- on-board memory stores up to 1,000,000 measurements
- communication range up to 70m line-of-sight
- low power consumption for extended use

Applications

- inclination & vibration testing and control
- security systems enabled by wireless sensor networks
- assembly line testing with "smart packaging"
- sports performance and sports medicine analysis
- condition- based maintenance by wireless sensor networks
- smart machines, smart structures, & smart materials

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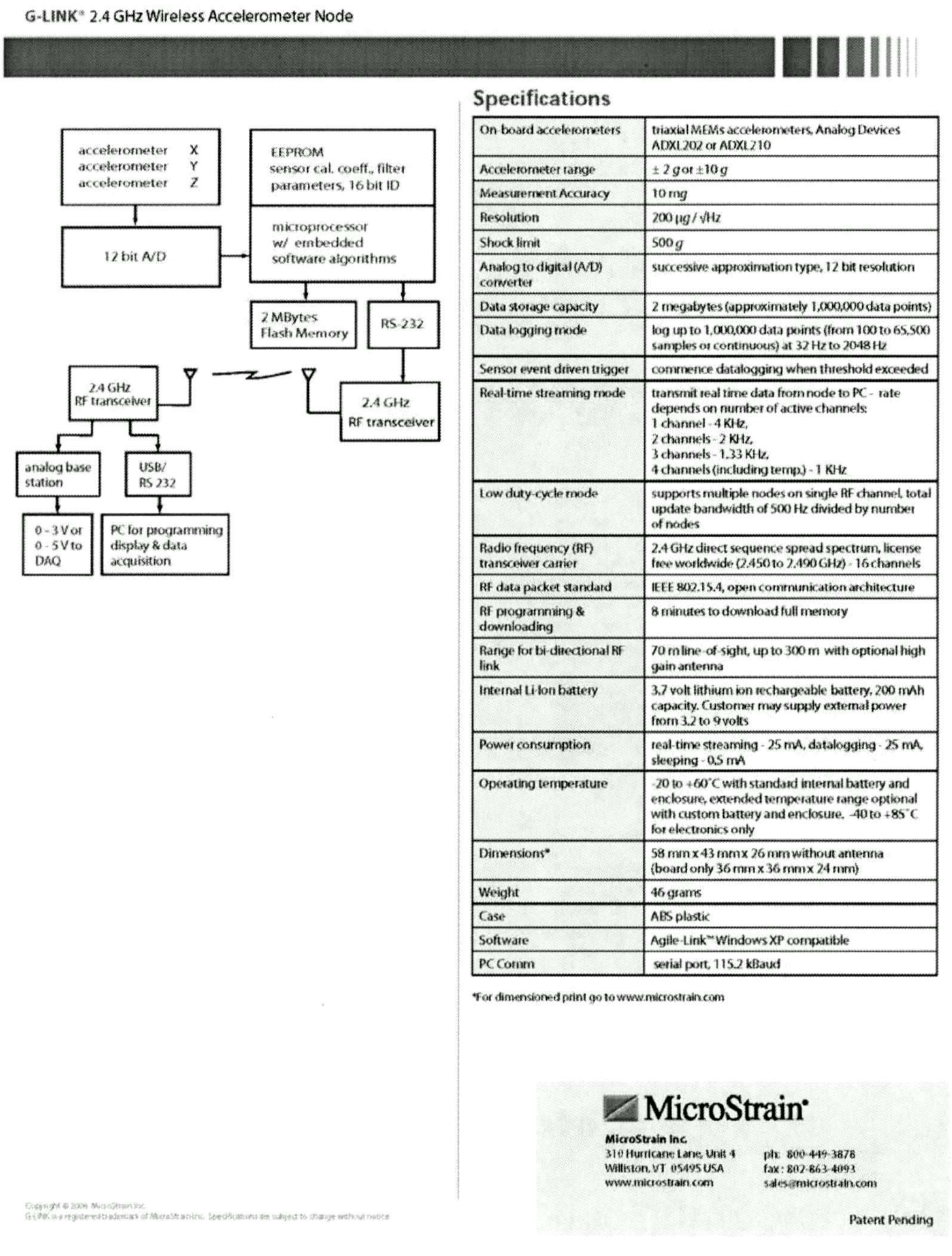

G-LINK® 2.4 GHz Wireless Accelerometer Node

Specifications

On-board accelerometers	triaxial MEMs accelerometers, Analog Devices ADXL202 or ADXL210
Accelerometer range	± 2 *g* or ±10 *g*
Measurement Accuracy	10 m*g*
Resolution	200 μ*g* / √Hz
Shock limit	500 *g*
Analog to digital (A/D) converter	successive approximation type, 12 bit resolution
Data storage capacity	2 megabytes (approximately 1,000,000 data points)
Data logging mode	log up to 1,000,000 data points (from 100 to 65,500 samples or continuous) at 32 Hz to 2048 Hz
Sensor event driven trigger	commence datalogging when threshold exceeded
Real-time streaming mode	transmit real time data from node to PC - rate depends on number of active channels: 1 channel - 4 KHz, 2 channels - 2 KHz, 3 channels - 1.33 KHz, 4 channels (including temp.) - 1 KHz
Low duty-cycle mode	supports multiple nodes on single RF channel, total update bandwidth of 500 Hz divided by number of nodes
Radio frequency (RF) transceiver carrier	2.4 GHz direct sequence spread spectrum, license free worldwide (2.450 to 2.490 GHz) - 16 channels
RF data packet standard	IEEE 802.15.4, open communication architecture
RF programming & downloading	8 minutes to download full memory
Range for bi-directional RF link	70 m line-of-sight, up to 300 m with optional high gain antenna
Internal Li-Ion battery	3.7 volt lithium ion rechargeable battery, 200 mAh capacity. Customer may supply external power from 3.2 to 9 volts
Power consumption	real-time streaming - 25 mA, datalogging - 25 mA, sleeping - 0.5 mA
Operating temperature	-20 to +60°C with standard internal battery and enclosure, extended temperature range optional with custom battery and enclosure. -40 to +85°C for electronics only
Dimensions*	58 mm x 43 mm x 26 mm without antenna (board only 36 mm x 36 mm x 24 mm)
Weight	46 grams
Case	ABS plastic
Software	Agile-Link™ Windows XP compatible
PC Comm	serial port, 115.2 kBaud

*For dimensioned print go to www.microstrain.com

MicroStrain®

MicroStrain Inc.
310 Hurricane Lane, Unit 4
Williston, VT 05495 USA
www.microstrain.com

ph: 800-449-3878
fax: 802-863-4093
sales@microstrain.com

Patent Pending

Technical Product Overview

Wireless Sensing System
2.4 GHz Wireless Base Stations

Introduction

2.4 GHz Base Stations are designed to operate as an integral part of any **Microstrain**® Wireless Sensing System high speed wireless sensor network. They provide seamless communication between a host PC, Single Board Computer or microcontroller and remote wireless nodes, including the **V-Link**® wireless voltage node, **SG-Link**® wireless strain node, **SG-Link**® OEM wireless module, **G-Link**® wireless accelerometer node and **TC-Link**® wireless thermocouple node.

The USB Base Station provides a plug-and-play USB connection. It is light-weight, easily-mountable, has a small footprint and can communicate individually with any **MicroStrain**® wireless node while issuing network instructions to multiple wireless nodes.

The Analog Base Station provides a plug-and-play USB or RS-232 connection. It has a small footprint, can be deployed as a stand-alone (without host PC) and can communicate individually with any wireless node as well as issue network instructions to multiple wireless nodes. It can also provide channelized data to analog data acquisition equipment in hybrid or legacy systems.

The Serial Base Station provides a plug-and-play RS-232 connection. It is light-weight, easily-mountable, has a small footprint and can communicate individually with any wireless node as well as issue network instructions to multiple wireless nodes.

Optional range extending antennas are available on request.

Features & Benefits

- 2.4 GHz direct sequence spread spectrum radio is license free worldwide
- IEEE 802.15.4 open communication architecture
- multiple base stations support simultaneous streaming from multiple nodes to PC
- support real-time streaming rates up to 4 KHz
- analog base station re-creates analog voltage for input into DAQ
- communication range up to 70 m line-of-sight, 300 m with high-gain antennas

Applications

- condition-based monitoring of machines
- health monitoring of civil structures and vehicles
- smart structures and materials
- experimental test and measurement
- robotics and machine automation
- vibration and acoustic noise testing
- sports performance and sports medicine analysis
- distributed security networks

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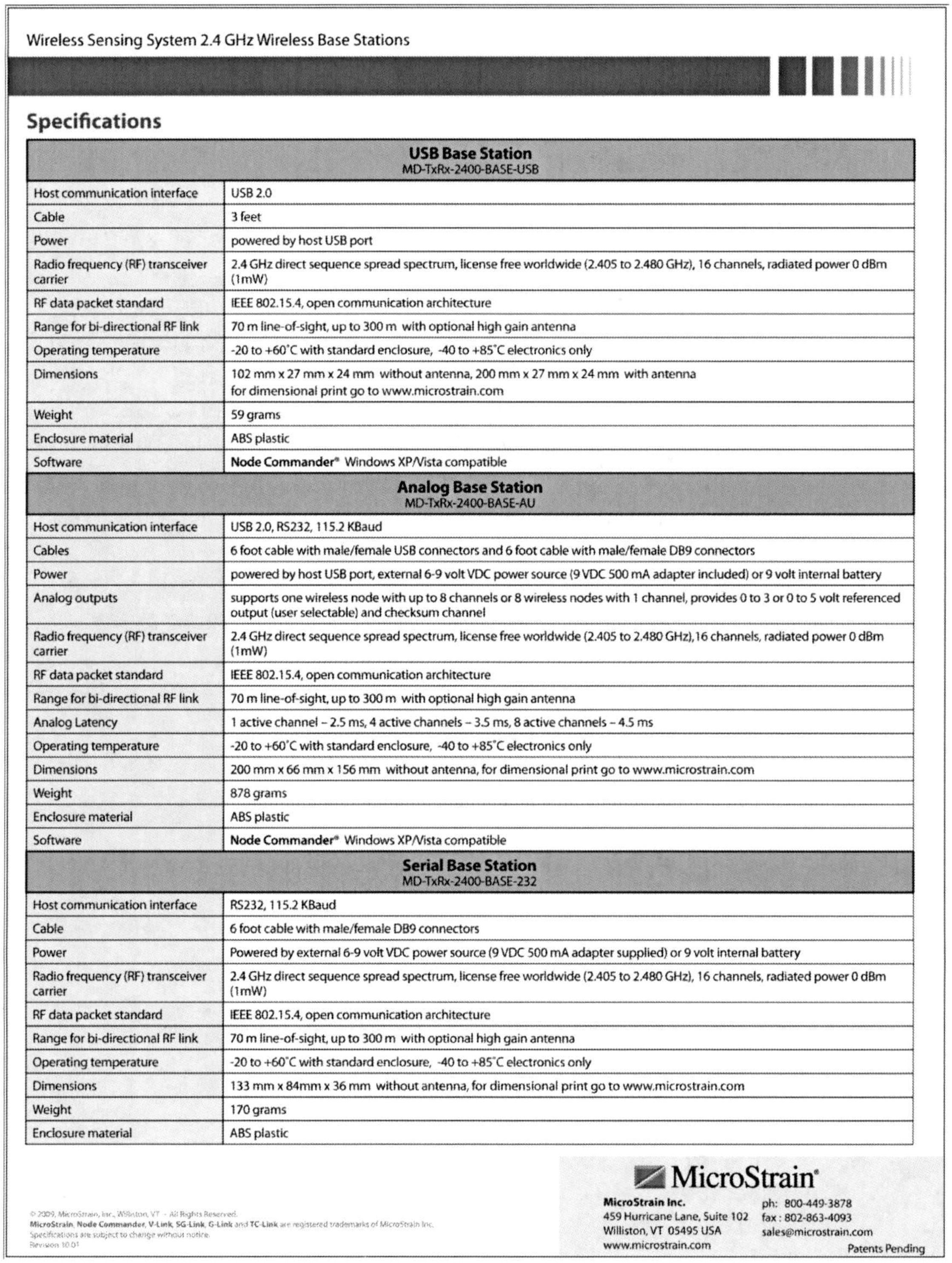

Wireless Sensing System 2.4 GHz Wireless Base Stations

Specifications

USB Base Station MD-TxRx-2400-BASE-USB	
Host communication interface	USB 2.0
Cable	3 feet
Power	powered by host USB port
Radio frequency (RF) transceiver carrier	2.4 GHz direct sequence spread spectrum, license free worldwide (2.405 to 2.480 GHz), 16 channels, radiated power 0 dBm (1mW)
RF data packet standard	IEEE 802.15.4, open communication architecture
Range for bi-directional RF link	70 m line-of-sight, up to 300 m with optional high gain antenna
Operating temperature	-20 to +60°C with standard enclosure, -40 to +85°C electronics only
Dimensions	102 mm x 27 mm x 24 mm without antenna, 200 mm x 27 mm x 24 mm with antenna for dimensional print go to www.microstrain.com
Weight	59 grams
Enclosure material	ABS plastic
Software	**Node Commander®** Windows XP/Vista compatible

Analog Base Station MD-TxRx-2400-BASE-AU	
Host communication interface	USB 2.0, RS232, 115.2 KBaud
Cables	6 foot cable with male/female USB connectors and 6 foot cable with male/female DB9 connectors
Power	powered by host USB port, external 6-9 volt VDC power source (9 VDC 500 mA adapter included) or 9 volt internal battery
Analog outputs	supports one wireless node with up to 8 channels or 8 wireless nodes with 1 channel, provides 0 to 3 or 0 to 5 volt referenced output (user selectable) and checksum channel
Radio frequency (RF) transceiver carrier	2.4 GHz direct sequence spread spectrum, license free worldwide (2.405 to 2.480 GHz),16 channels, radiated power 0 dBm (1mW)
RF data packet standard	IEEE 802.15.4, open communication architecture
Range for bi-directional RF link	70 m line-of-sight, up to 300 m with optional high gain antenna
Analog Latency	1 active channel - 2.5 ms, 4 active channels - 3.5 ms, 8 active channels - 4.5 ms
Operating temperature	-20 to +60°C with standard enclosure, -40 to +85°C electronics only
Dimensions	200 mm x 66 mm x 156 mm without antenna, for dimensional print go to www.microstrain.com
Weight	878 grams
Enclosure material	ABS plastic
Software	**Node Commander®** Windows XP/Vista compatible

Serial Base Station MD-TxRx-2400-BASE-232	
Host communication interface	RS232, 115.2 KBaud
Cable	6 foot cable with male/female DB9 connectors
Power	Powered by external 6-9 volt VDC power source (9 VDC 500 mA adapter supplied) or 9 volt internal battery
Radio frequency (RF) transceiver carrier	2.4 GHz direct sequence spread spectrum, license free worldwide (2.405 to 2.480 GHz), 16 channels, radiated power 0 dBm (1mW)
RF data packet standard	IEEE 802.15.4, open communication architecture
Range for bi-directional RF link	70 m line-of-sight, up to 300 m with optional high gain antenna
Operating temperature	-20 to +60°C with standard enclosure, -40 to +85°C electronics only
Dimensions	133 mm x 84mm x 36 mm without antenna, for dimensional print go to www.microstrain.com
Weight	170 grams
Enclosure material	ABS plastic

Revision 10.01

MicroStrain®

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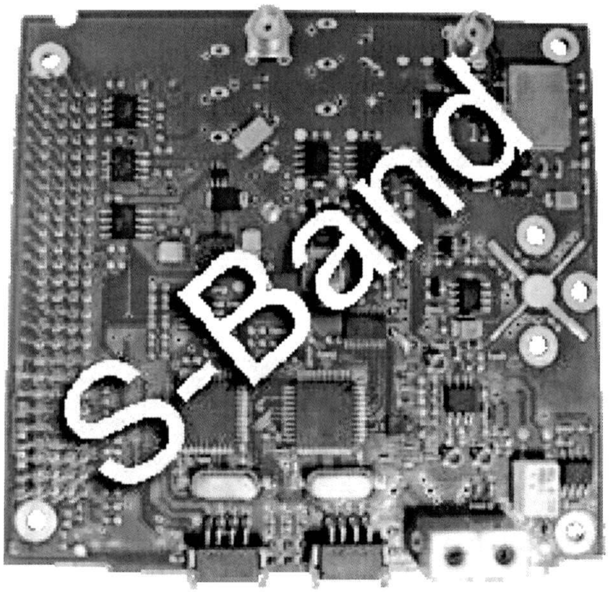
Patents Pending

Transmitters



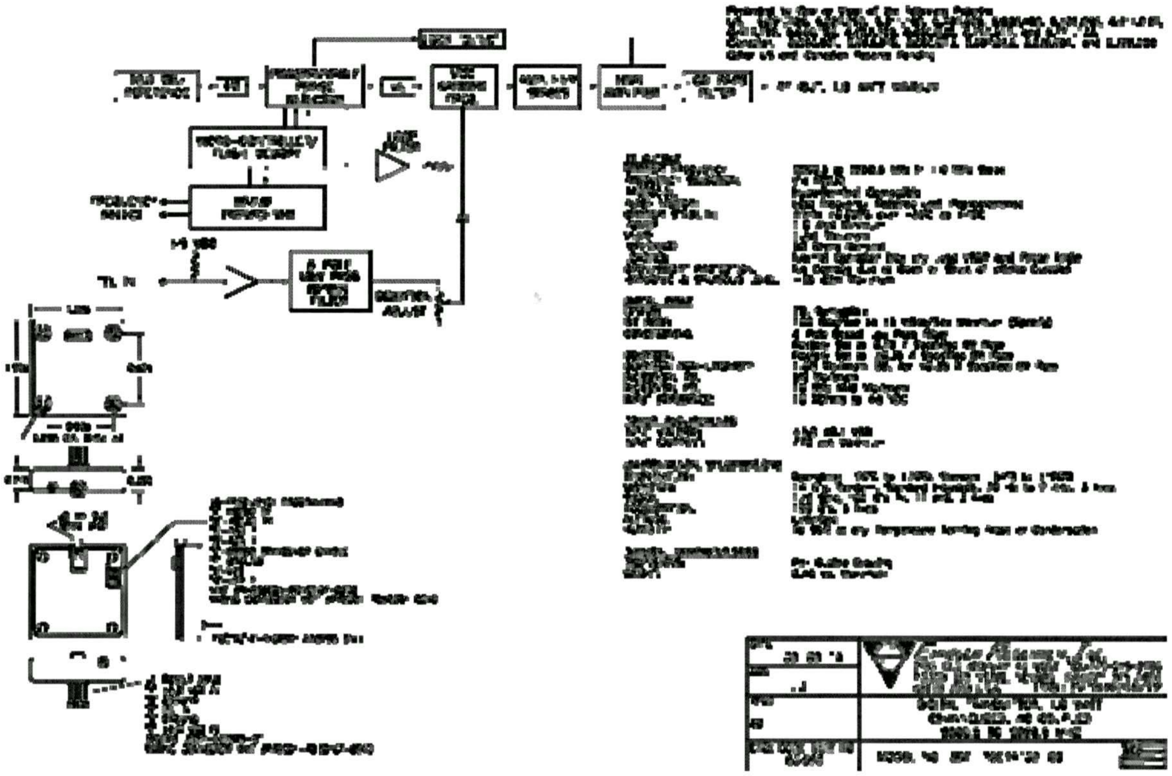
Clyde Space S Band Transmitter

The TXS is a transmitter module designed specifically for nano-satellite application. It is compatible with the CubeSat standard and the CubeSatKit bus and standard CubeSat structures. The TXS transmitter works at S-band frequencies of 2100 MHZ to 2500 MHz. TXS can handle data rate transmission up to 115 kbps, while featuring a low power consumption. The TXS transmitter supports BPSK, QPSK, and GMSK modulation schemes.

- Application for LEO
- Fixed RF frequency range: 2100 MHz-2500 MHz
- Data rates: Up to 115 kbps
- RF output power : Up to 30 dBm
- Modulation : BPSK, QPSK, GMSK
- Frequency accuracy: +/- 10 kHz
- Frequency stability: 20 ppm
- VSWR : 1.5
- Supply Voltage: 6-30 VDC
- Output Impedance: 50 Ohm
- Mass: < 125 grams
- Form Factor: 90x96x40 mm (PC/104 compatible)
- Power Consumption: 2W
- Interfaces:
    - RF SMA
    - Data: I2C
    - PCB: PC/104 (cubesat kit compatible)
- Thermal Range: -40° to +85° C
- Qualification Levels: PSLV levels

- Available options:
    - Variable Data Rate
    - Higher output power
    - CAN bus interface

Other transmitter option



Appendix C: Interface Documents

The interface documents detail the individual connectors between sub-systems or within the same sub-system described above.

Wireless Accelerometers

The wireless accelerometers, by design, are quite different from the wired variety. Aside from the method of data transmission there are some other very important differences. These differences affect the wireless accelerometers will interface with the rest of the CubeSat, especially the A/D converter.

The first difference is a result of the nature of the transmission. Since these sensors are delivering the data wirelessly, the receiver is what needs to be interfaced with the A/D converter. The selected converter has multiple pins for digital and analog inputs alike, meaning that there will be numerous options regardless of the type of data transmitted to the converter.

Another prominent difference is that the wireless accelerometer includes a programmable signal amplifier and A/D converter within its structure. This means that all data gathered by the wireless accelerometers is gathered in digital, converted to digital and then sent to the receiver. The significance of this difference is that the receiver will need to be connected to one of the digital input pins on the main A/D converters.

Together these differences will free a total of three analog input pins for the system overall. It will also reduce the workload of the main A/D converters since these three sensor's data will not need to be converted from analog to digital prior to being stored.

Wired Accelerometers

The wired accelerometers, unlike the wireless variety, only record their data in analog. These sensors are designed to transmit the data through a provided wire to an A/D converter. The 20 Pin connector interface provides 20 tin clamps that can receive the wires from various sources (power supply, thermocouple, accelerometers, ground, etc). With the pin schematic, the wired sensors can be connected through the pin connector to the A/D converter in the proper pin slot. This will assure that the data wire remains fashioned to the A/D converter for the duration of the launch. From this point, the A/D converter will interface with the storage unit.

External Transmission System

To connect the ISIS TXS S-band transmitter to the TECOM S-band antenna 401163-7 a RF SMA, I2C or PCB: PC/104 to TNC female connection must be found. The RF SMA to TNC female connection was chosen and a connector was found. The connector is from RFAC Solutions with a part number of R410-111 SMA RP Plug to TNC Jack. A R410-014 or R410-015 might work depending on the transmitter's compatibility.

Thermocouple

The diagram of the interface between the thermocouple sensor and the A/D converter is depicted below. The chosen 2 Lead Terminal temperature transducer can be wired directly to the A/D converter by use of a retention contact. The A/D converter has a 20-Pin configuration matching to the shown 276-1992 20-Pin Retention Contact. The breakdown of data pin designation is as follows: 1-9 are digital outputs, 11-15 are digital inputs, and 16-19 are analog inputs. Connecting wires will be used to extend the 2 terminals of the thermocouple to the proper location of the A/D converter being used.

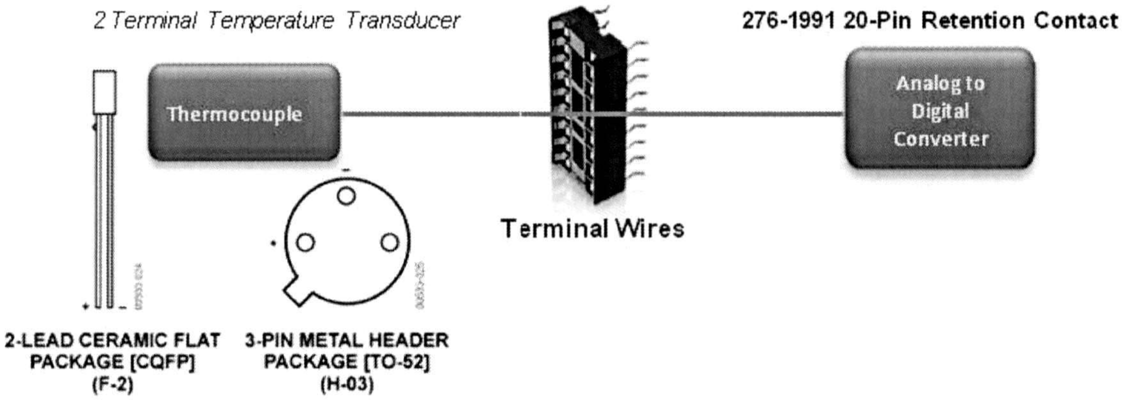


Figure 27: Thermocouple Interface Diagram

Note that the same 20-Pin contact can be used to directly interface with the EPS and USB storage device, with pins 10 and 20 being the ground and live power respectively. As mentioned in the C-specifications of the A/D converter, there is a front end op-amp contained within AD670S so the interface of a separate amplifier is not necessary.

Camera

In order to connect the camera to the USB storage device, the signal must first be routed into an in-housing digital video recorder link together with a SpaceWire, a common way to transfer data within satellites. The SpaceWire may be purchased with the proper 9-pin connector to interface the camera with the DVR and the DVR to the USB storage device. As seen in the FFD the streaming camera data undergoes signal conditioning and is then sent to an A/D converter. The diagram pictured below shows a breakdown of the FBD of the ECAM-C30 DVR and how it relates to the final storage.

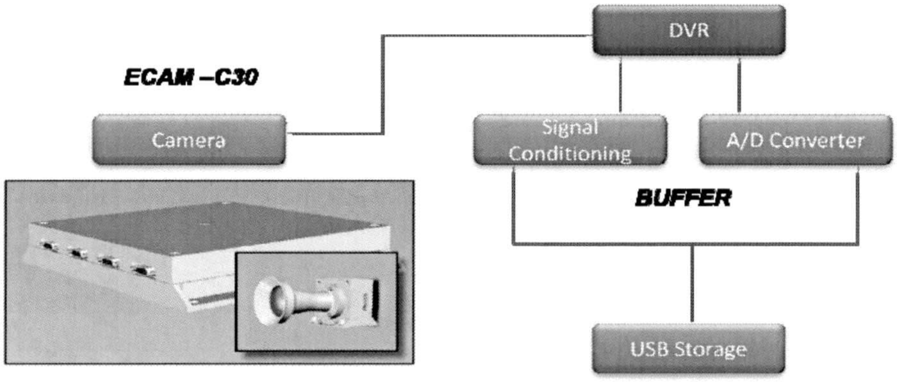


Figure 28: Camera Interface Diagram

The camera housing as discussed in the C-Specifications operates on an 8 V source and has its own separate terminals within the space certified housing.

Data Storage Unit

One area of concern is in regards to the interface of the data storage unit. On the front end, the connection between the unit and the A/D converter, everything is understood. Much like the front end of the A/D converter, the outputs of that device are included in the 20 pin connection.

The issue with the data storage unit occurs between the unit and the S-band transmitter. Current documentation does not specify the type of input connection on the ISIS TXS S-Band transmitter. Conventional wisdom states that there will be a connection point via a pin connector or soldering point on the transmitter's circuitry board. Since no contact was made with the retailers outside of requests for data sheets the exact specifications for the input of the transmitter is currently unknown. Future work and contact of the products supplier would easily clarify any and all uncertainties about the layout and configuration of the interface between the storage unit and the transmitter.

Appendix D: Reliability

Understanding system reliability is important when considering the useful life a system. Reliability is the probability of zero failures as a function of time. In order to do so, the Mean Time Between Failure (MTBF) must be known. The failure rate, λ, is the inverse of the MTBF. Reliability is defined in Equation 1.

$$R(t) = e^{-\lambda t} \qquad [1]$$

Table 8 is the reliability analysis for the CubeSat system at the end of its design life, 24 hours. MTBF data was used when available. If MTBF data was unavailable, MTBF for similar items was used. According to Shaun Daly, who works at NASA Hanger AE on CCAFS, NASA's satellite programs are designed with a life expectancy of 10 years. To remain conservative, if MTBF for electronic items could not be found, the MTBF was assumed to be five years or 43800 hours. Mechanical features were given an assumed MTBF between 10 and 20 years (87600-175200 hrs). Since there are no redundancies in our system, the system reliability is simply the product of individual component reliabilities.

Item	MTBF (hrs)	Failure Rate (λ)	R(t)
Chassis	87600	1.142E-05	0.99973
Cover Plate	87600	1.142E-05	0.99973
Base Plate	87600	1.142E-05	0.99973
"Remove" Bracket	175200	5.708E-06	0.99986
Transmitter	43800	2.283E-05	0.99945
S-band Antenna	1000000	1.000E-06	0.99998
Camera Chip	43800	2.283E-05	0.99945
Camera Housing	43800	2.283E-05	0.99945
Thermocouple	43800	2.283E-05	0.99945
Digital Converters	43800	2.283E-05	0.99945
Wired Accelerometers	43800	2.283E-05	0.99945
Wireless Accelerometers	43800	2.283E-05	0.99945
Battery	43800	2.283E-05	0.99945
EPS	43800	2.283E-05	0.99945
Amplifier	43800	2.283E-05	0.99945
Data Storage	87600	1.142E-05	0.99973
Processor	43800	2.283E-05	0.99945
Misc. Wires/bolts	175200	5.708E-06	0.99986
Insulation	131400	7.610E-06	0.99982
Time	24	hrs	
System Reliability	99.242	%	

Table 16: System Reliability

As seen in Table 18, MTBF for most items could not be found and assumptions were made. With the assumptions made, the system reliability over a 24 hour period is .9907.

All electronics and components of the CubeSat system will go through an extensive testing process. These tests will include: vibration, thermal, micro-gravity, as well as other testing. All of the testing will be conducted to the standards required by NASA.