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Trailblazer: Proof of Concept CubeSat Mission for SPA-1

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The Space Plug-and-play Architecture (SPA) concept of rapid satellite development has progressed exponentially over the past several years. The team at the Configurable Space Microsystems Innovations and Applications Center (COSMIAC) in conjunction with the Space Dynamics Laboratory (SDL) and the Air Force Research Laboratory have trained over 500 individuals on this rapid bus architecture related to satellite development. This paper will outline the first CubeSat satellite proof of concept flight for a SPA only spacecraft. The Trailblazer mission is designed to fly a 1U CubeSat that is based entirely on a SPA bus implementation. Trailblazer will consist of Commercial Off The Shelf (COTS) parts converted to be SPA compliant. This allows not only a demonstration of the bus reliability in a space environment, but also the ease in converting existing components to be SPA compliant. With the dimensional constraints and power budget of Trailblazer, we have elected to use the SPA-1 standard. SPA-1 is the most recent addition to the AFRL SPA family. The SPA-1 data transfer protocol is based on 400 kbit/s I2C making it the lowest power, and lowest bandwidth option for SPA. Given the power constraints of typical satellite architecture, it is generally advantageous to interface devices/modules which do not require high data transfer rates to a SPA network via the SPA-1 Applique Sensor Interface Module (ASIM). This ASIM is logic that enables SPA Plug-and-Play for hardware components. It contains all the information needed for the system to automatically discover and automatically configure the hardware component. SPA-1 ASIMs can be any microcontroller that supports I2C and has enough memory to contain the needed logic. This allows the standard to remain open to a variety of dynamic implementations. The Trailblazer mission is being launched under the National Aeronautics and Space Administration (NASA) Educational Launch of Nanosatellite (ELaNA) program. This NASA program is designed to provide affordable access to space through collaborative efforts with academic institutions. The ELaNA program provides manifesting and launch of CubeSats for $30,000 per 1U module. The proposed orbit is 325 km with an inclination of 51 degrees for a launch in 2011.

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I. Why SPA?

Traditional satellite development is both costly and generally has a timeframe measured in years. The overall mission of the Trailblazer project was to go from satellite design to delivery in under a year. This aggressive schedule was promoted due to the requirement to launch additional satellites of different sizes and complexities in future years. The best way to accomplish this was through a system where components could be added or removed in a modular format similar to a home computer. The SPA paradigm was chosen since it provided an open source design medium for utilizing a well established bus architecture.[1][2][3] Each module was chosen based on its proven functionality and reliability. These parts were then modified to make them SPA-1 compatible to show the ease of performing this operation. In collaboration with the Space Dynamics Laboratory (SDL) we were able to create a full satellite within one year with SPA-1 modules that can be reused in future spacecraft. Development continues with the AIAA technical committee to advance the standards of SPA. However, the real benefit is the ability to inexpensively launch space assets to physically test modules and systems as the documents related to the standards continue to be developed. New programs such as the NASA Educational Launch of Nanosatellites (ELaNA) programs are working to solve this.[4]

II. SPA-1 ASIM Overview

At the heart of SPA lies the Applique Sensor Interface Module (ASIM). This module serves as the primary interface between the PnP network and the individual components. As such, it is essential that we optimize the ASIM for a multitude of applications, thus there is no one-size-fits-all version. Based on a PIC micro controller and a two wire data transfer protocol known as I2C, the SPA-1 ASIM is the most minimalistic of these versions. It is an ultra compact, and ultra low power option for those sensors that do not require a high bandwidth interface.

There are currently three separate development teams working in close collaboration on SPA-1. Each individual effort concentrates on one of the three tiers of SPA-1. The first tier is the most simplistic, built completely from commercial-off-the-shelf (COTS) parts; this will be the most economical option for SPA-1. These ASIMS can be ordered for well under $100 per unit and serve the purpose of familiarizing component developers with the SPA-1 protocol. The second tier ASIM is again based on inexpensive COTS parts, but packaged in a 10X10 mm co-fired ceramic. It is electrically identical to the tier 1 ASIM. There are two companies working on the final tier of SPA-1: AAC Microtec (Sweden)[5] and Micro-RDC (New Mexico).[6]

In the COTS versions discussed above, a physical PIC microcontroller is present in the design. The hardened parts have the unique advantage of being pin-for-pin and footprint compatible with the inexpensive COTS versions. This enables developers to design and test their boards with economical parts, then seamlessly transition to more expensive flight hardware.

III. SPA Services Manager

The Space Dynamics Laboratory has developed a reference implementation of the SPA Standards. This implementation is called the SPA Services Manager (SSM). The SSM is responsible to component discovery, component registration, data centric queries, time distribution, and internal systems health monitoring and status reporting. These functions are accomplished by multiple SPA Subnet Managers, a Central Addressing Service (CAS) and a Lookup Service.

A SPA Subnet Manager is responsible for performing discovery on a subnet. On Trailblazer the SPA subnet that is being used is SPA-1. The SPA-1 Subnet Manager discovers each component on the SPA-1 subnet and reports it to the Lookup Service. The SPA-1 Subnet Manager also monitors the connection with each SPA-1 component and if it fails, alerts the Lookup Service which in turn alerts other components that are using the data products from the SPA-1 component that failed. This allows for fault tolerance and status monitoring.

The Central Address Service assigns address blocks to SPA Subnet Manager. This allows to each subnet to have a unique address space ensuring that there are no duplicate addresses in the SPA Network. The Lookup Service is the core component that takes a components xTEDS[7] and allows other components to perform queries on it. This enables the data plug and play capabilities on SPA. If I have a component that needs temperature data, it would issue a query to the Lookup Service for temperature data, which in turn would respond with the addresses of all components capable of providing temperature data. The component would then select a data source and subscribe to the temperature data. These three core SSM components enable a system to use SPA.

IV. Trailblazer Overview

The Trailblazer mission is to prove the reliability and robustness of a SPA based satellite in a space environment. Trailblazer will also show the ease of modifying current COTS parts to function on a SPA network. The satellite consists of a 1U CubeSat structure and COTS parts, modified to be SPA compliant. It is set to launch in October of 2011 at an orbit of 325km, 51 degrees. In addition to the main mission, Trailblazer will also contain a SPA-1 Dosimeter to measure the effects of the South Atlantic Anomaly (SAA); and a SPA-1 rapid prototyped analog to Digital Converter (ADC) control board to test new advancements in 3D PCB design for space applications. Each subsystem, or SPA module, was created as an individual SPA component. The focus of each SPA module design was on how that subsystem would be used by all satellites. The Command and Data Handler (C&DH) for the SPA network would contain the necessary software for this missions specific need. Utilizing this design methodology would allow the work accomplished on Trailblazer to be directly applied to later missions without modification to any of the SPA modules. This new approach to satellite development has the ability to reduce both cost and development time for space missions.

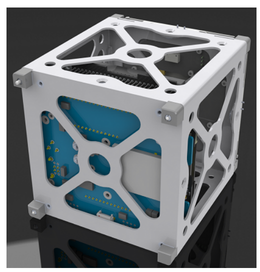

Figure 1. Solidworks rendering of the Trailblazer satellite

V. Trailblazer Subsystems

Trailblazer is constructed from commercial off-the-shelf parts (COTS). It was the intent of the Trailblazer team to show how existing components can be converted to meet SPA standards. What follows is a brief description of each subassembly:

A. Command and Data Handler (C&DH)

The C&DH sits on top of the Pumpkin motherboard. The Pumpkin Corporation has a long history of making successful flight hardware.[8] The C&DH is responsible for handling the SPA-1 network and processing the information passed along that network. The functions of a SPA manager are to discover new devices within the network, register those devices, parse through the xTEDs, and create a registry that maps out the network.

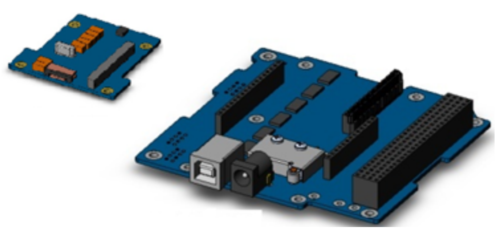

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Figure 2. Pumpkin Command and Data Handler.

As you can see in figure 2, the C&DH consists of two parts. The first part is the Pumpkin motherboard and the smaller module in the back is the Pluggable Processor Module.

B. Passive Magnetic Attitude Stabilization System (PMASS)

Since CubeSats carry a low mass, the use of a magnetic stabilizing rod works very well to control tumble in orbit. The rod aligns the CubeSat with Earth's magnetic field. This allows for reasonable attitude control without the need for any applied power. The PMASS houses permanent magnet and dampers for stabilization around the Z axis.

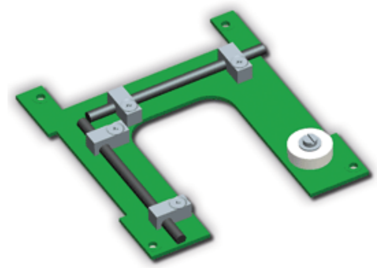

Figure 3. ISIS PMASS.

The PMASS unit shown in figure 3 is from the ISIS Corporation and is created to allow it to fit within the standard CubeSat structure.

C. Electrical Power System (EPS)

The power system was manufactured by Clydespace[9] . An ASIM was added to the system so that it will function on a SPA-1 network. The EPS comes with an attached 20Whr battery. The power system also includes six high efficiency UTJ solar cells. This system will provide all the power information that will be used by the C&DH to make decisions relating to power usage. The system will use a battery charge management system for charging the lithium batteries. It will provide 3.3V, 5V and raw battery busses with over-current protection.

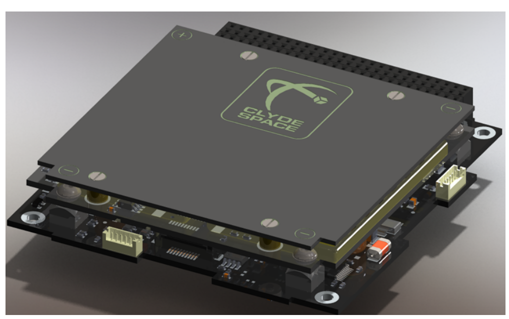

Figure 4. Electrical Power System (solar panels and batteries not shown).

As you can see in figure 4, the EPS is designed to fit into a 1U section of a CubeSat and solar panels will mount on all six sides of the satellite.

D. Payloads

Trailblazer will contain two payloads. The first will be a Dosimeter to measure the radiation experienced in the South Atlantic Anomaly (SAA). The Plug-n-Play dosimeter monitors the accumulation of ionizing radiation. This is accomplished with a depletion mode, p-channel RadFet from REM which is fabricated with a thick oxide to maximize its sensitivity to radiation. An ASIC from Nu-Trek Corporation[10] called the NuDose is configured to force a specified current through the RadFet. As radiation penetrates the oxide in the RadFet, electron-hole pairs are created and then separated via the electric field in the dielectric. The positive charge drifts toward the conduction channel and becomes trapped in the oxide. This modifies the threshold voltage of the device, and consequently changes the resistance between the source and drain electrodes. The NuDose must maintain the selected current through the Fet and thus the voltage across the source and drain must increase to compensate for the increased channel resistance. This voltage is sent out to and external ADC on the SPA-1 ASIM. The ASIM can be configured to periodically transmit the 10bit binary number corresponding to this voltage via the SPA-1 I2C bus. If a periodic message is not desired, the user can set up a request message that will only transmit data upon a request command.

The second payload will be a rapid prototyped Inertial Measurement Unit (IMU). This payload will test a new 3-D PCB design methodology. 3-D PCB design can improve the limited volume available found on each CubeSat mission by filling in the open space with critical electronics. In addition, the IMU may provide a low power, low cost solution to position acquisition. As with the rest of the satellite, these payloads have been fitted with an ASIM to make them SPA-1 compliant and to facilitate their use in future satellites.

The University of Texas at El Pasos W. M. Keck Center for 3D Innovation[11] is a premier lab focusing on Additive Manufacturing a technology that was invented almost 25 years ago in order to fabricate three-dimensional prototypes, but more recently is evolving to be used in manufacturing highly-customized 3D finished products. If you haven't heard of the term Additive Manufacturing before, a more intuitive description is 3D printing and an analogy can be made between printing a 2D picture from your home computer. As a common printer today will print a 2D image on paper, Additive Manufacturing allows one to print a CAD model of a 3D object (say a coffee mug for instance) layer by layer in a 3D printer and have the mug custom-fit for you specifically with the imprint of their fingers in the handle. You could then print a customized coffee mug for each member of your family with the same printer.

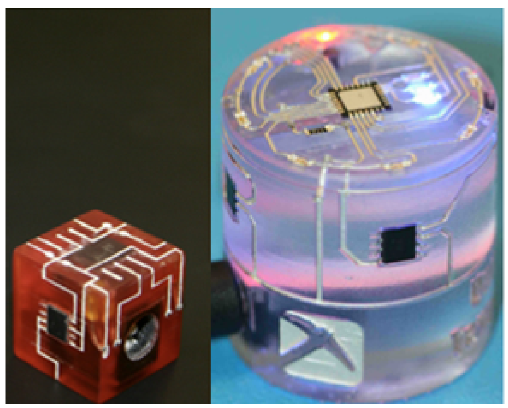

Figure 5. UTEP 3D Project.

The Keck Center can fabricate 3D objects that are plastic, metal, of bio-compatible materials or that contain electronics. An example is shown in figure 5. A recent focus for the center is on structural electronics in which electronics can be fabricated in a 3D structures of arbitrary and complex shape in order to accommodate human anatomy - possibly for wearable computing or custom-fit intelligent prosthetics. Or simply to replace structural components in satellites, planes, cars or furniture with equivalent structures that contain intelligence with embedded electronics. The applications of this technology are only limited by ones imagination and one day you will eventually be able to download a file and - in your house print your next 4G cell phone.

A recent collaboration between the University of New Mexicos COSMIAC and UTEPs Keck Center is resulting in an electronics structure being launched in a CubeSat Satellite in August.

E. Communications

The communication system will consist of an Astrodev Helium 100 radio and an ISIS deployable antenna. Again, each component has been fitted with an ASIM to be SPA-1 compliant. The frequency range will be within the armature band. This will allow the HAM community to assist in data collection. Transmission to the satellite will be in the VHF band and reception at the ground station will be in the UHF band.

As shown in figure 6, the Astrodev radio and the ISIS antenna will be mated to perform the VHF/UHF communications functions.

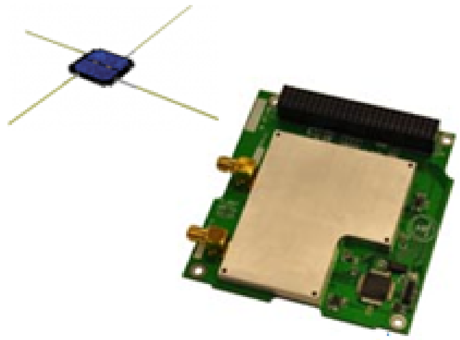

Figure 6. The ISIS Antenna (with deployer) and Astrodev Radio are shown.

Trailblazer will also try to utilize the Global Educational Network for Satellite Operations (GENSO) ground station network. GENSO provides ground stations around the world. This will provide a great asset to utilize when tracking Trailblazer within the first three months. By staying within the armature band we can assure that COTS communication equipment will be more than sufficient.

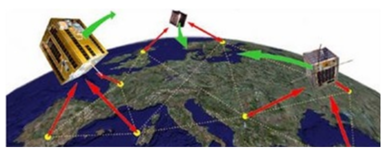

Figure 7. GENSO Model of Operations

GENSO provides a hub-spoke configuration that will allow ground stations around the globe to be able to receive AX.25 packet data from our satellite. As shown in figure 7, the GENSO network allows multiple ground stations to be able to download mission data and provide the consolidated data to satellite owner. This ability to receive data from more than one ground station greatly increases the ability to receive critical health and science data in a more timely fashion.[12]

F. Structure

To reduce the weight, the Pumpkin skeletonized structure was chosen. The structure is a standard 1U enclosure with space on top for the deployable antenna system.

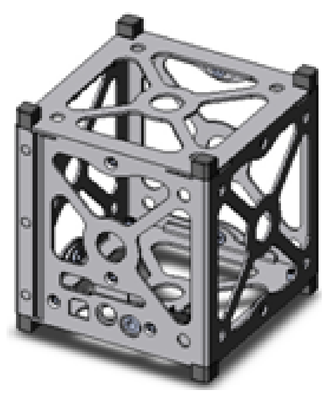

Figure 8. CubeSat 1U Satellite Structure.

The structure shown in figure 8 is made of 8051 aluminium and contains two separation springs and two separation switches on the four corners of the legs. It is designed to fit into the standard Cal Poly PPOD deployer. The benefit of using this structure is that it has proven flight heritage as well as the known ability to provide access to remove before flight interfaces.

VI. Results

As of February 2011, all purchase orders for parts have been issued and frequency allocation requests have begun. The GENSO network is being tested daily to ensure reliability. SPA module and system software is being developed and tested. Solidworks and STK software is being utilized to perform analysis on mission parameters. Thermal and vaccum testing is scheduled to be completed this summer.

VII. Conclusion

It is the opinion of the team that this satellite can provide a testbed for showing the capabilities and exploit the opportunities that can only be achieved in space through the use of an open bus architecture for satellites.

Acknowledgements

We would like to strongly recognize the guidance and involvement of Dr. Jim Lyke of the Air Force Research Laboratory for his support in having the vision for SPA and in helping the team to stay on schedule. We would also like to thank Jim White, WD0E, of Colorado Satellite Services for helping to act as the guiding light on this entire activity. He has forgotten more about building satellites than most folks will ever learn.

References

[1]Moore, G., Holemans, W., Huang, A., Lee, J., McMullen, M., White, J., Twiggs, R., Malphrus, B., Fite, N., Klumpar, D., Mosleh, E., Mashburn, K., Wilt, D., Lyke, J., Davis, S., Bradley, W., Chiasson, T., Heberle, J., and Patterson, P., "3D Printing and MEMS Propulsion for the RAMPART 2U CUBESAT," *Proceedings of the 24th Annual Conference on Small Satellites*, Logan, UT, 8-11 August 2010.

[2]Morphopouolos, T., H. L. P. J. L. J. and Cannon, S., "Plug-and-Play-An enabling Capability for Responisve Space Missions," *Responsive Space Conference, Los Angeles, CA*, 2004.

[3]McNutt, C. and Lyke, J., "CubeFlow: A Modular Open Systems Architecture for CubeSats," *Proceedings of the 7th Responsive Space Conference*, Los Angeles, CA, 27-29 April 2009.

[4]Link, I., "NASA ELaNa Internet Notification," http://www.nasa.gov/offices/education/centers/kennedy/technology/elana_feature.html, 2011.

[5]Link, I., "AAC Angstrom Website," http://www.aacmicrotec.com/index.php/home.html, 2011.

[6]Link, I., "MRDC Website," http://www.micro-rdc.com/index.html, 2011.

[7]Craig J. Kief, Jacob Christensen, B. H. and Mee, J., "CubeFlow: Training for a New Space Community," AIAA, April 2010.

[8]Link, I., "Pumpkin Website," www.cubesatkit.com, 2011.

[9]Link, I., "Clyde Space Website," http://www.clyde-space.com/cubesat_shop/eps/8_1u-cubesat-eps, 2011.

[10]"Nu-Trek Corporation," 2011.

[11]"University of Texas El Paso," 2011.

[12]Link, I., "GENSO Web Site," http://www.genso.org/, 2011.