A CubeSat Design to Validate the Virtex-5 FPGA for Spaceborne Image Processing

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Abstract—The Earth Sciences Decadal Survey identifies a multiangle, multispectral, high-accuracy polarization imager as one requirement for the Aerosol-Cloud-Ecosystem (ACE) mission. JPL has been developing a Multiangle SpectroPolarimetric Imager (MSPI) as a candidate to fill this need. A key technology development needed for MSPI is on-board signal processing to calculate polarimetry data as imaged by each of the 9 cameras forming the instrument. With funding from NASA's Advanced Information Systems Technology (AIST) Program, JPL is solving the real-time data processing requirements to demonstrate, for the first time, how signal data at 95 Mbytes/sec over 16-channels for each of the 9 multiangle cameras in the spaceborne instrument can be reduced on-board to 0.45 Mbytes/sec. This will produce the intensity and polarization data needed to characterize aerosol and cloud microphysical properties. Using the Xilinx Virtex-5 FPGA platform, a polarimetric processing least-squares fitting algorithm is under development to meet MSPI's on-board processing (OBP) requirements. The Virtex-5 FPGA is not yet space-flight qualified; however, an in-flight validation of this technology on a pre-cursor CubeSat mission is valuable toward advancing the technology readiness level for MSPI and the ACE mission. [1,2]

The Michigan Multipurpose Minisatellite (M-Cubed) is a CubeSat under development by students at the University of Michigan in the Student Space Systems Fabrication Lab (S3FL). The satellite meets the California Polytechnic Institute's (CalPoly's) specifications for a 1U CubeSat. M-Cubed's primary mission objective is to obtain quality color images of the Earth from Low Earth Orbit (LEO). M-Cubed's primary payload is an IDS UI-1646LE-C 1.3 MegaPixel CMOS Camera that will take the images and save them to a Colibri PXA270 Microprocessor. The camera has a resolution of 1280x1024 pixels, each with a size of 3.6 x 3.6 micrometers. This allows for moderate to high-resolution images of the Earth after post-processing. With the current system, there is enough excess volume, power, and mass to support an additional payload. In order for M-Cubed to carry out any additional objectives using other payloads, the attitude, power, mass, volume, and communication capabilities must be compatible.

This paper describes the collaborative efforts between the University of Michigan M-Cubed team and JPL's MSPI OBP team to define an integrated CubeSat payload to demonstrate the Xilinx Virtex-5 MSPI OBP algorithm by processing images from the M-Cubed CMOS camera. The outcome of a feasibility study will be described as it pertains to design requirements, payload architecture, interface design, mission objectives, and operational scenarios to advance this collaborative concept toward implementation in 2010.

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[1] 978-1-4244-3888-4/10/$25.00 ©2010 IEEE.
[2] IEEEAC paper 1246, Version 3, January 2, 2010

1 INTRODUCTION

The Michigan Multipurpose Minisatellite (M-Cubed) is a 1U CubeSat that will carry JPL's image processing payload. The satellite bus will be composed of in-house, student-developed spacecraft subsystems built from Commercial Off-The-Shelf (COTS) hardware. A custom 1U CubeSat structure houses electronics boards for power distribution and command and data handling. Triple-junction solar cells provide power to the bus during sunlight while Lithium Ion batteries provide spacecraft power during eclipse periods. An Atmel microcontroller serves as the main onboard processor, providing the command interface for the payload interface module, the JPL payload (MSPI OBP algorithm), and the telemetry subsystem. Communication is accomplished through amateur radio with on-board COTS radios and a permanent ground station at the University of Michigan. The CubeSat will be passive-magnetically stabilized through the use of permanent magnets and hysteresis material, allowing the camera payload to image the northern hemisphere. While no launch has been manifested, M-Cubed is discussing an opportunity for launch to a near polar orbit with an altitude between 500-800 km (based on heritage CubeSat launches). Following launch, M-Cubed will be operated through the ground station at the University of Michigan. After initial operations checkout, image data will be downlinked, and the relevant JPL processing data will be provided to the JPL PIs for analysis.

The proposed JPL MSPI processor will be adapted to the M-Cubed payload package. The main components of the payload are: a Xilinx Virtex-5 FPGA; an 8051 or similar microcontroller; SRAM; and configuration memory (PROM). In order to reduce energy consumption, only the microcontroller will be continuously powered, controlling the power to the remaining components as necessary (i.e., only when processing data) and providing the SPI (serial peripheral interface) interface to M-Cubed's main processor. The JPL payload will process images collected by the M-Cubed camera. The results of this onboard data-processing will be downlinked along with the M-Cubed payload image data. On the ground, the source image from M-Cubed's camera will be re-processed and the output compared to that of the onboard processor.

2 TECHNOLOGY DESCRIPTION

2.1 M-Cubed Capabilities

M-Cubed is a 1U imager CubeSat using a CMOS camera to take a high-resolution image of the Earth. The satellite will be launched into a yet undetermined orbit and will use a passive magnetic control system to align with the Earth's magnetic field. With this configuration, the command and data handling (C&DH) subsystem will command the payload interface processer to schedule the camera to take a picture of the Earth. This picture will be packaged for transmission and sent to the telemetry subsystem to transmit the image down to the ground station. An in-house developed Electrical Power System (EPS) will power the camera payload, JPL payload, C&DH, and telemetry subsystems. The EPS uses onboard solar cells to charge a Rose Lithium-Ion battery pack through Direct Energy Transfer (DET). All of these subsystems will be housed and supported by a custom-built structure conforming to the CalPoly 1U CubeSat specifications.

2.2 M-Cubed Subsystem Highlights

2.2.1 Primary Payload

M-Cubed's primary payload is an IDS UI-1646LE-C 1.3 MegaPixel CMOS Camera with a 9.6 mm EFL (effective focal length) Plano-convex lens (Figure 1). The camera will take an image and save it to a Colibri PXA270 Microprocessor at a resolution of 1280x1024 pixels, each pixel with a size of 3.6 x 3.6 micrometers. This allows for moderate to high-resolution images of the Earth after post-processing. Even with the lens positioned at the correct focal length, the whole camera payload subsystem is fairly small and takes up only 55 cm^3 of space.

Figure 1. M-Cubed Camera Payload [2]

2.2.2 Orbits & Controls

CubeSats are secondary payloads on launch vehicles, and since no flight is scheduled yet, M-Cubed does not currently have a defined orbit. However, heritage suggests that a sun-synchronous orbit of inclination 98° and altitude between 500 and 800 kilometers can be expected. For attitude control, M-Cubed will implement passive magnetic stabilization using a permanent magnet and two hysteresis strips. This system provides a pointing accuracy between five and ten degrees along the Earth's magnetic field meeting the requirements of the camera payload. With this stabilization, M-Cubed is capable of taking pictures of the Earth in the northern hemisphere. This system provides an excellent platform for establishing flight heritage for additional components.

2.2.3 Electrical & Power Subsystem

The M-Cubed Electrical Power System (EPS) consists of a 3.3V and 5V bus regulated by buck boost DC-DC converters, Emcore BTJM solar cells, a 3.7V, 2.2 A-hr Rose Lithium-ion battery pack, a LTC2309 Analog to Digital

Converter (ADC), and a variety of health monitoring sensors. Currently, M-Cubed has three modes of operation: standby (charging), picture taking and image processing, and downlink. The power specifications for the three modes are shown in Table 1 below.

Table 1. Power Specifications for Operating Modes

	MODES OF OPERATION (sunlit: 59.96 min, eclipse: 35.21 min)		
Energy (per orbit)	**Standby**	**Picture Taking, Image Processing**	**Downlink**
Generated (watt-min)	103.20	103.20	103.20
Consumed (watt-min)	59.97	71.69	81.29
Battery recharge (watt-min)	43.23	31.51	21.91
Battery depletion (orbits)	never	125.14	26.47

The table above is a rough estimate of the power consumption / generation per mode of operation. Constant average current draw is assumed for the computation of the number of orbits necessary for battery depletion. This will likely not occur during actual operation, where, for example, the power-demanding downlink operation could be avoided during eclipse times and rescheduled for completion during full exposure to sunlight.

2.2.4 *Command, Data Handling, and Telemetry*

The command and data handling (C&DH) subsystem uses an ATmega164P microcontroller to control satellite operations. This processor is powered on at all times and is monitored by an external watchdog timer. The system operates at 8 MHz on a 3.3 V bus and can communicate over SPI, I2C, and USART protocols. USART is used to communicate with and control the radio transceivers. An I2C bus is implemented to communicate with the payload PXA270 and the EPS health data. Currently, all the USART connections are used, but output connections are available on both SPI and I2C for additional communication if necessary. The processor speed can reach 20 MHz if moved to a 5 V bus, though this is not currently planned.

M-Cubed will use amateur radio bands for communication. The telemetry subsystem consists of a 16.5 cm antenna transmitter at 430 MHz and a 45 cm antenna receiver at 140 MHz. The antennas act as dipoles and will be constructed from spring steel. Based on simulation, an average downlink time of about 5 minutes to Ann Arbor is expected, compared to an uplink time of 10 minutes per pass. Additionally, the minimum signal power that can be received by the transceivers at 140 MHz is -114 dBm. Finally, all image transmissions are controlled by ground station operations software developed in-house to ensure the downlinked pictures meet requirements.

2.2.5 *Structures*

The M-Cubed structure has been developed in-house according to CalPoly's CubeSat specification. It consists of six iso-grid aluminum 7075 panels and four aluminum 6061 hard anodized rails. The current structure has a Safety Factor of 6 under the launch load of the Minotaur IV launch vehicle, the worst case scenario. The next iteration of the structure will reduce the safety factor to 1.5 or above in order to minimize the mass. The structure has enough volume to add a secondary payload since only about half of the volume is being used. Currently 87% of the 1 kg allotted mass is being used, with 30% contingency on components that have not been measured and 5% for those which have been. The mass budget also includes a 100 g system contingency allowing for the secondary payload to be accommodated within M-Cubed.

2.3 *JPL FPGA Payload*

The JPL payload is an FPGA-based computing platform that implements the On-Board Processing (OBP) algorithm designed for a future camera instrument called MSPI [3].

2.3.1 *MSPI Background*

Multiangle SpectroPolarimetic Imager (MSPI) is a JPL instrument development for the proposed Decadal Survey ACE (Aerosol-Cloud-Ecosystem) mission. In the MSPI design, a dual photoelastic modulator (PEM) assembly is integrated into a polarization-preserving 3-element reflector to provide both intensity and polarization imaging. A miniaturized focal-plane assembly consisting of spectral filters and patterned wire-grid polarizers provides color and polarimetric selection. A custom CMOS array with specialized signal acquisition, readout, and processing electronics captures the radiometric and polarimetric information.

2.3.2 *OBP Objectives*

The algorithm used to process the polarization channels involves the following steps:

- In hardware, de-multiplex the incoming data stream. Use ancillary information provided about the PEM amplitudes and phases, and time stamps of the subframes within each frame to calculate a set of "basis functions".
- In software, create the polarization measurement matrix B, comprised of the sampled basis functions, and calculate its pseudoinverse W.
- Load the W operator into hardware, and then apply it to the sampled measurements using matrix multiplication to retrieve the desired polarization parameter estimates.

The basis functions are analytic expressions (consisting of trigonometric and Bessel functions) of the PEM mean retardance amplitude, amplitude difference, the PEM average and difference frequencies, and the integration interval durations and sample locations within the frame. These sample times vary slightly from row to row.

A single 16-channel MSPI camera (1 of 9) must process 95 Mbytes/sec of raw video data; data reduction to 0.45 Mbytes/sec is required. Although this requirement makes it seem that this is a compression algorithm, there is a subtle and fundamental difference. The input data stream is oversampled: we are applying an estimation and extraction process, not compression.

2.3.3 MSPI OBP Algorithm Description

For a complete mathematical description of the MSPI OBP algorithm, see journal article in *Applied Optics* [4]. IEEE Aerospace Conference papers from 2009 and 2010 provide a concise overview of the algorithm with an emphasis on implementation details [3][5]. In what follows, reference Figure 2 as an OBP block-diagram.

The OBP accepts a dark-corrected pixel and ancillary data stream. On the start of a subframe, pixel data is separated from ancillary and timing data. Ancillary and timing data are stored in separate processor-accessible buffers and pixel data is passed into a subframe-sized buffer. When the subframe buffer fills, data is fed into a floating-point matrix multiplier (realized with a serial combination of: fixed-point-to-floating-point converter, floating-point multiplier, floating-point adder, and correct-length FIFO). After an entire frame has been processed, the results are copied into a persistent FIFO and the processor signals the PowerPC microprocessor (PPC) via an interrupt. Upon receiving an interrupt, the PPC sets up a DMA transfer from the persistent FIFO and ancillary data buffer to system output and collects timing information. If the timing has changed significantly, the PPC software uses the timing information to recalculate the matrix used in the hardware matrix multiply and reloads it. Otherwise the same matrix is used.

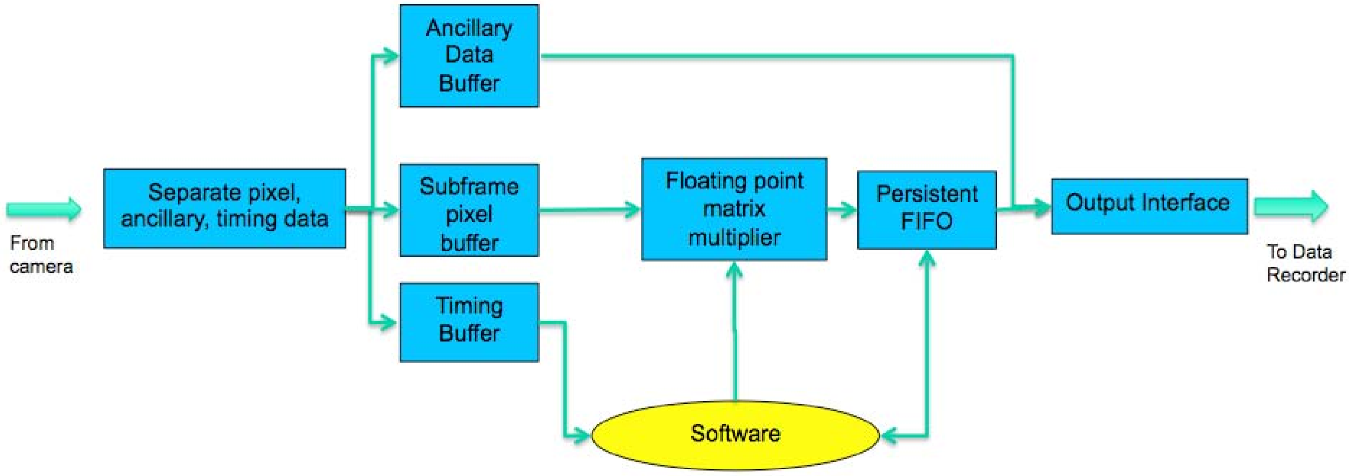

Figure 2. MSPI Implementation Data Flow

Because the MSPI instrument measures fundamentally different data than the COTS camera on M-Cubed, the implementation of the algorithm on M-Cubed is slightly modified on a few points:

1) MSPI is designed to produce data with polarimetric information mixed into the pixel intensities; the M-Cubed camera yields only intensities. In addition, electronics in the MSPI instrument provides sample timing information to the onboard processor for polarimetric extraction. We will use a subset of pixel data as a surrogate for timing information, and then either directly apply the polarimetric extraction algorithm to the remainder of the pixels, or use this to simulate the mixing of polarimetric information followed by direct application of the polarimetric extraction algorithm.

2) The MSPI camera produces a continuous data stream, whereas the M-Cubed camera will provide static images. Normally, quasistatic, yet slightly out-of-date, timing values are used to process a particular camera frame. For M-Cubed, we will use timing information (as discussed above) generated for a particular image to process that same image.

In practice these differences amount to small changes in the “glue” connecting subcomponents together: the vast majority of the algorithm is unchanged between the two implementations.

2.3.4 Xilinx Virtex-5 FPGA Capabilities

The MSPI OBP algorithm is implemented in the Xilinx Virtex-5FXT FPGA. An FPGA was chosen for its inherent flexibility in interfacing and optimized performance for image processing design. In particular, the Virtex-5FXT FPGA was chosen for its high-performance features and continuing efforts by Xilinx on developing a radiation hardened version to be available in the near future [6]. Among the sought-after features are the embedded PowerPC 440 processor, the hard crossbar switch, and abundant logic resources.

The V5FXT FPGA contains an embedded superscalar processor, the PowerPC440, an upgrade to previous generation's single issue PowerPC 405 processor. The new PPC440 processor, shown in Figure 3 has 32 KB data and 32 KB instruction caches with data and instruction buses that are 32-bit instruction / 36-bit address / 128-bit data wide. Larger cache sizes and wider system buses can play a significant role in optimizing performance by hiding memory access latency (with more cache hits) and moving more bits simultaneously between system peripherals. The hard 5 x 2 crossbar switch in particular helps the later by providing in-silicon point-to-point connections between processor and memory / bus interfaces [7].

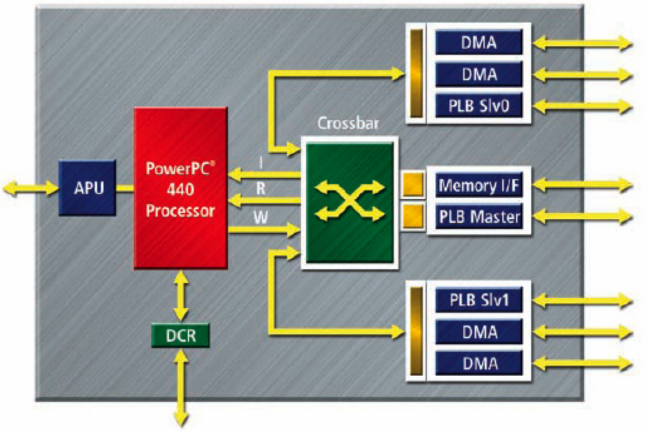

Figure 3. PowerPC 440 embedded processor block and 5 x 2 hard crossbar switch [7]

To compute the pseudoinverse matrix W, the auxiliary processor unit (APU) controller of the PPC440 is used to offload floating-point arithmetic to the soft-core single-precision floating-point unit (FPU). The APU allows for the connection of soft co-processor units (such as the FPU) directly into the processor's instruction decoding pipeline. This achieves a tremendous reduction in latency as data is moved directly from the processor to the co-processor without experiencing any bus contention. The soft-core FPU can provide up to 6x improved floating-point performance over software emulation.

The heart of the MSPI OBP algorithm relies on floating-point matrix multiplication implemented from logic resources on the FPGA. The V5FXT contains many embedded RAM blocks (BRAM) and dedicated hardware multipliers (DSP48), which are required for this computation. The surrounding logic resources can run at up to 550 MHz, providing a high speed link to BRAM and DSP48 blocks from the rest of the system.

3 IMPLEMENTATION DESCRIPTION

3.1 FPGA Payload Architecture

There are four major elements to the FPGA payload architecture: an FPGA, configuration PROM, SRAM, and a microprocessor. In addition, several minor components, including voltage regulators and oscillators, are needed to support the major elements. A block diagram of the FPGA payload architecture is shown in Figure 4. The FPGA requires at least two voltages – 1V and 2.5V. Depending on the exact parts selected (microcontroller, PROM, SRAM), other system voltages may also be necessary and can be regulated down from the supplied bus voltages. Separate oscillators are required to provide system clocks to the FPGA and microcontroller. Due to the fact that different processing rates affect the current draw of the FPGA and the power budget has not been finalized, the details of the oscillator for the FPGA are still being evaluated. The PROM will be used to configure the FPGA once it is powered up. The SRAM will be used to store data before and after it has been processed. The microprocessor will be used to control the data flow into and out of the payload hardware. The intent is to use SPI for communications between all the main components of the payload architecture.

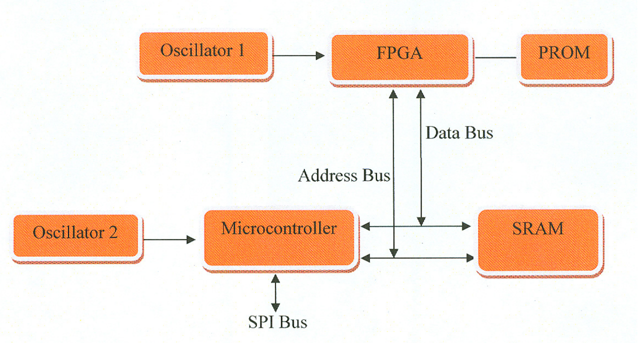

Figure 4. JPL Payload Block Diagram

3.2 Interfaces

A standard interface providing power and communication will be provided between the M-Cubed spacecraft bus and the JPL FPGA payload.

3.2.1 Power

M-Cubed will provide 5 V and 3.3 V buses to the JPL payload. Each bus will be rated for a maximum of 2.25 A continuous current draw.

The expected power consumption of the MSPI OBP payload is 10 watts for at most 10 seconds per image processed.

3.2.2 Communications

An SPI communication bus will be used for control and data transfer between the JPL payload and the M-Cubed C&DH subsystem. The camera data will be sent directly from the Colibri PXA 270 microprocessor on the M-cubed bus to an 8051-series, or similar, microcontroller on the MSPI payload. The microcontroller will load the data into SRAM for storage, where it awaits processing by the FGPA. Once the data is processed and ground communication is ready, the results will be sent back to the M-Cubed bus for downlink. The energy consumption of the PXA 270 is acceptable within the M-Cubed operational architecture.

3.3 Preliminary Structural Design

The FPGA payload will be housed on a modified PC-104 board that also houses the primary payload. The modification consists of removing a small area from one side to allow the imager to sit at the correct distance from the outside. The board will include a custom header to interface with the C&DH board.

The mounting scheme of the FPGA board will depend on its mass. The board will either sit on the C&DH board or be directly connected to the top and bottom sides of the structure. If it is light enough to sit on the C&DH board, it will do so through standard aluminum board standoffs that provide thermal conduction. If the weight exceeds a certain limit, it will be mounted directly to the top and bottom panels through aluminum blocks that also provide conduction paths. Finite element analysis for both inertial and vibration loads will drive the configuration. The analysis will also ensure all the components conform to the safety factor of 1.5.

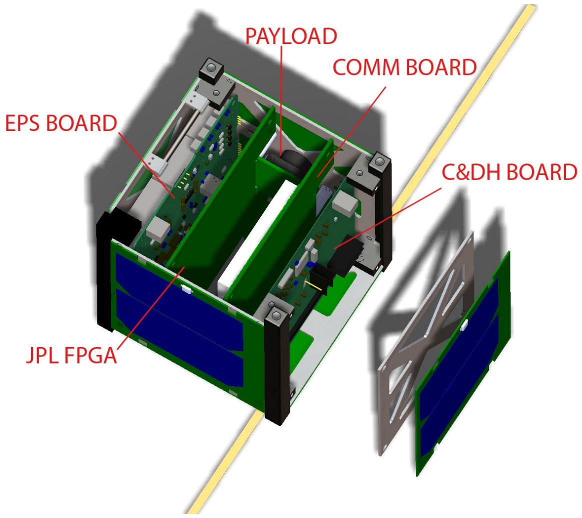

Figure 5. M-Cubed Computer Aided Drawing with JPL FPGA Payload

3.4 Preliminary Operational Design

After de-tumbling to align with the Earth's magnetic field in orbit, M-Cubed's mission operations will begin. After start-up, M-Cubed has three distinct modes of operation that it will undergo to take a picture and downlink it. The three modes of operation are as follows:

- Stand-by
  - No processing or camera operation
  - Health beacon at 13% duty cycle
- Picture Taking and Processing
  - Camera, Virtex 5 FPGA, and payload processor at 1% duty cycle
  - Health beacon at 11% duty cycle
- Downlink
  - No processing or camera operation
  - Transmit processed image to ground station

During nominal operations, M-Cubed will receive a message from the ground station scheduling a time to take a picture. M-Cubed will remain in stand-by mode until the scheduled time, and then transition to picture taking and processing mode. In this mode, M-Cubed will take the scheduled picture and begin processing the image with both the payload processor and the Virtex 5 FPGA. After processing, M-Cubed will enter downlink mode and begin transmitting the processed image to the ground station at the next pass opportunity.

4 FUTURE WORK

Though the collaboration between The University of Michigan and JPL is well underway, there are still many things left to be done to accomplish the objectives of the M-Cubed mission and the MSPI payload. The design of the MSPI payload still needs to be completed, and the modified algorithm developed at JPL needs to be implemented. Hardware trades will be done and components will be selected for the JPL payload hardware. Then the JPL payload needs to be built and tested. Once this is complete, the JPL payload will be integrated into the M-Cubed CubeSat. There is also the continued collaborative effort between JPL and the University of Michigan to secure a launch opportunity.

5 CONCLUSION

JPL has been developing a Multiangle SpectroPolarimetric Imager (MSPI) to fulfill hardware needs for the Aerosol-Cloud-Ecosystem (ACE) mission. As part of meeting the real-time data processing requirements to demonstrate that signal data at 95 Mbytes/sec over 16-channels for each of the 9 multiangle cameras in the spaceborne instrument can be reduced on-board to 0.45 Mbytes/sec, JPL is working on the Xilinx Virtex-5 FPGA platform. Using this platform, a polarimetric processing least-squares fitting algorithm is under development to meet MSPI's on-board processing requirements. The Virtex-5 FPGA is not space-flight qualified; however, an in-flight validation of this technology on a pre-cursor CubeSat mission would be valuable toward advancing the technology readiness levels for MSPI and the ACE mission. To this end, JPL and the University of Michigan are working together to use M-Cubed as a test platform. Many of the ideas outlined in this paper are being developed to advance this collaborative concept toward implementation in 2010.

6 ACKNOWLEDGEMENTS

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8 BIOGRAPHY

Dmitriy Bekker is a Staff Engineer in the Instrument Flight and GSE Software group in the Instrument Software and Science Data Systems Section at JPL. He is currently working on FPGA-based data acquisition and processing design for multiple prototype science instruments. His areas of interests include FPGAs, embedded systems, digital signal processing, and system architecture. Dmitriy received his M.S. and B.S. degrees in Computer Engineering from Rochester Institute of Technology in 2007.

Thomas Werne is a Staff Engineer in the Instrument Flight and GSE Software group in the Instrument Software and Science Data Systems Section at JPL. He is currently working on implementing FPGA-based technology for Smart Payload applications. Thomas has Bachelor of Science degrees in Electrical Engineering and Mathematics, a Master of Electrical and Computer Engineering from Rose-Hulman Institute of Technology in Terre Haute, IN, and is currently enrolled as a Ph.D. Student in Control and Dynamical Systems at Caltech. He is a member of IEEE.

Thor Wilson is an Electronics Engineer I in the Flight Instrument Electronics Implementation group at JPL. He is currently working as a liaison between university CubeSat programs and JPL, specifically interfacing the MSPI payload to the MCubed bus. Thor has Bachelor of Science degrees in Aerospace Engineering and Physics from Auburn University. He worked for three years as a student on a CubeSat project, Aubiesat-1, at Auburn.

Paula Pingree is Supervisor of the Flight Instrument electronics group in the Instruments and Science Data Systems Division at JPL, and Principal Investigator for the AIST "Optimizing MSPI Design for the ACE Mission" technology task. She has been a key contributor to the design, integration, test and operation of several JPL flight projects including Cassini, Mars Global Surveyor, Deep Space 1, and Deep Impact. Most recently she led the Electronics development for the Microwave Radiometer instrument on the Juno spacecraft planned for a 2011 launch to Jupiter. Ms. Pingree has a Bachelor of Engineering degree in Electrical Engineering from Stevens Institute of Technology in Hoboken, NJ, and a Master of Science in Electrical Engineering from California State University Northridge. She is a member of IEEE.

Kiril Dontchev is a 2nd year masters student in Space Systems Engineering at the University of Michigan. He was part of the team that originally conceived M-Cubed on a napkin in 2007 and since then, has graduated with his B.S in Aerospace Engineering from the University of Michigan. He is the acting program manager on M-Cubed, an EPS engineer for M-Cubed and Michigan's other CubeSat RAX, an S3FL executive committee advisor. Following graduation, he plans on pursuing a career in small satellite entrepreneurship. He is a member of AIAA.

Michael Heywood is a senior in Aerospace Engineering at the University of Michigan with a minor in Physics. He is Chief Engineer of M-Cubed and also working on the Attitude Determination and Control Systems team for the Radio Aurora Explorer under development at Michigan. Upon receiving his Bachelors of Science in Aerospace Engineering, Michael will go for a Masters of Engineering Space Systems from the University of Michigan.

Rafael Ramos is a doctoral student in the Design Science Program, with a concentration in Space Systems Design at the University of Michigan. His research focuses on the design of complex systems; design modeling and information flow to facilitate knowledge re-use and innovation. In recent years, he has been member of the Executive Committee of the Student Space Systems Fabrication Laboratory (S3FL) at the University of Michigan. He has a Master of Engineering in Space Systems from the same institution. He is a member of AIAA.

Bradley Freyberg has been the Command and Data Handling team lead since the founding of M-Cubed in 2007. He recently graduated with his B.S.E in Computer Engineering from the University of Michigan and will pursue a Masters degree in Space Systems Engineering. On M-Cubed he has concentrated on system design and software development. He is a member of AIAA.

Fernando Saca is a 1st year masters student in Space Systems Engineering at the University of Michigan. He has a B.S.E in Mechanical Engineering with a minor in Multi-Disciplinary Design. He has been involved with M-Cubed since its start and is currently the Structures and Thermal lead. He is also involved with the Radio Aurora Explorer at the University of Michigan developing and building solar panels and performing thermal analysis.

Brian Gilchrist is a Professor of Electrical Engineering and Space Science at UM with multiple space flight instrument experience. He is a long-time faculty advisor for S3FL (including M-Cubed) and other teams. He currently is Founding Director for Michigan's new Multidisciplinary Design Program and is actively assisting in the development in new student opportunities such as the Nanosatellite Pipeline. He will continue as an M-Cubed faculty advisor and help facilitate equipment use (e.g., thermal-vacuum chamber) and mentorship of students from engineers at UM's Space Physics Research Laboratory (SPRL) at UM.

Alec Gallimore, Arthur F. Thurnau Professor of Aerospace Engineering at UM, is the Director of the NASA Michigan Space Grant Consortium (MSGC). Professor Gallimore has extensive experience in electric propulsion research and thruster development for NASA and the U.S. Air Force. He will provide administrative oversight of project activities at UM and integrate these activities with MSGC educational, research, and public outreach initiatives. Professor Gallimore will also ensure that the student body for this project reflects the diversity of our nation by recruiting women and underrepresented minorities.

James Cutler is an assistant professor in the Aerospace Engineering Department at the University of Michigan. His research interests center on space systems--a multidisciplinary approach to enabling future space capability with particular emphasis on novel, nanosatellite missions. He is developing next generation communication capability and robust space computing infrastructure. He is Co-PI on the first NSF space mission, the Radio Aurora Explorer (RAX). Prof. Cutler's teaching interests are in all things space related.