Real-Time On-Board Processing Validation of MSPI Ground Camera Images

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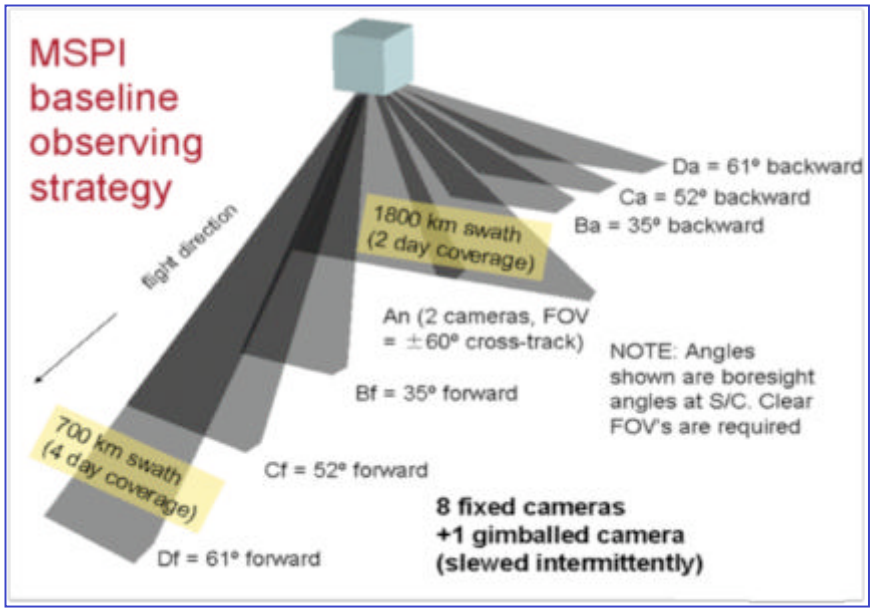
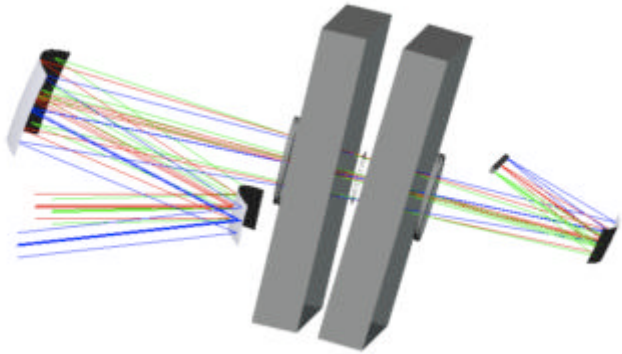
Multi-angle SpectroPolarimetric Imager (MSPI)

- Measures cloud and aerosol properties
- 8-fixed and 1-gimballed cameras, each with 16 channels
- Design goals
  - Acquire accurate multispectral intensity imagery
  - Acquire accurate degree of linear polarization (DOLP) imagery
- Two photo-elastic modulators (PEMs) in optical path for high accuracy in DOLP
- A single MSPI camera must process 95 Mbytes/sec of raw video data; data reduction to 0.45 Mbytes/sec is required



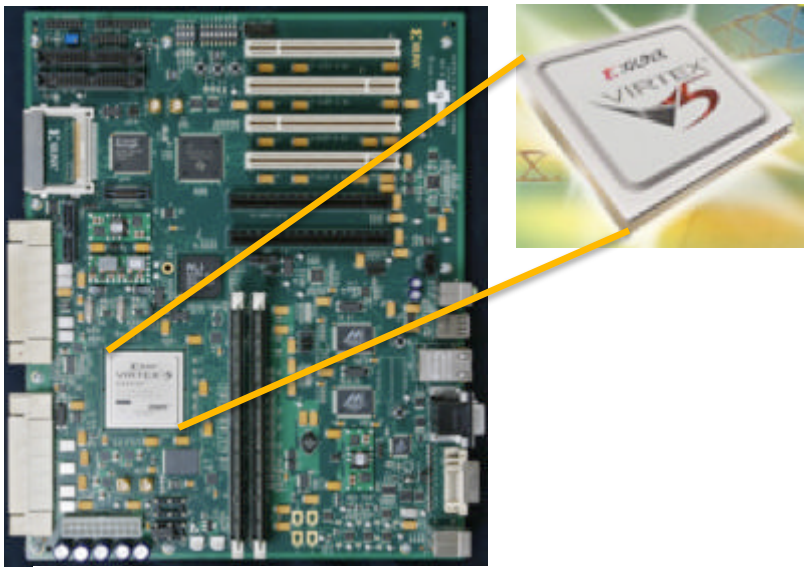


The information technology processing challenge is to apply on-board processing to extract intensity and polarimetric parameters from the real-time data stream across each camera thereby reducing the data volume by 2-orders of magnitude without loss of science information.

AIST-08-035 Task Summary

- On-Board Processing (OBP) to Optimize the MSPI Imaging System for ACE
  - PI: Paula Pingree, Co-Is: Thomas Werne, Dmitriy Bekker
- Objectives:
  - Design an on-board instrument processing system to reduce the data rate by more than two orders of magnitude to meet the spectro-polarimetric image processing requirements for the MSPI instrument.

➢ We implement the MSPI OBP algorithm on the Xilinx Virtex-5FXT FPGA



ML 510 Development Board

Key Milestones

Migrate/modify Virtex-4 linear least-squares processing to Virtex-5 system	09/09
Integrate FPGA development board system into MSPI camera brass-board in laboratory	06/10
Finish design trades on algorithm implementation to optimize performance	12/10
Finish design trades on other DSP train operations to simplify camera design	06/11
Test (airborne pending availability) integrated system on real-time data acquisition	02/12

Algorithm Overview

- Goal is to obtain polarization parameter estimates (*<I,Q,U,V> Stokes* vectors) and Degree of Linear Polarization, DOLP (a function of these parameters)

$$\mathrm{DOLP} = \sqrt{(Q/I)^2 + (U/I)^2} = \sqrt{q^2 + u^2}$$

$$\begin{pmatrix} I_{0,1} \\ \vdots \\ I_{0,n} \end{pmatrix} = B \begin{pmatrix} I \\ \nabla I \\ Q \\ \nabla Q \end{pmatrix}$$

- Pixel array is divided into three segments
  - *I0 channel – horizontally-oriented polarizer*
  - *I45 channel – 45° oriented polarizer*
  - *I channel – no polarizer*

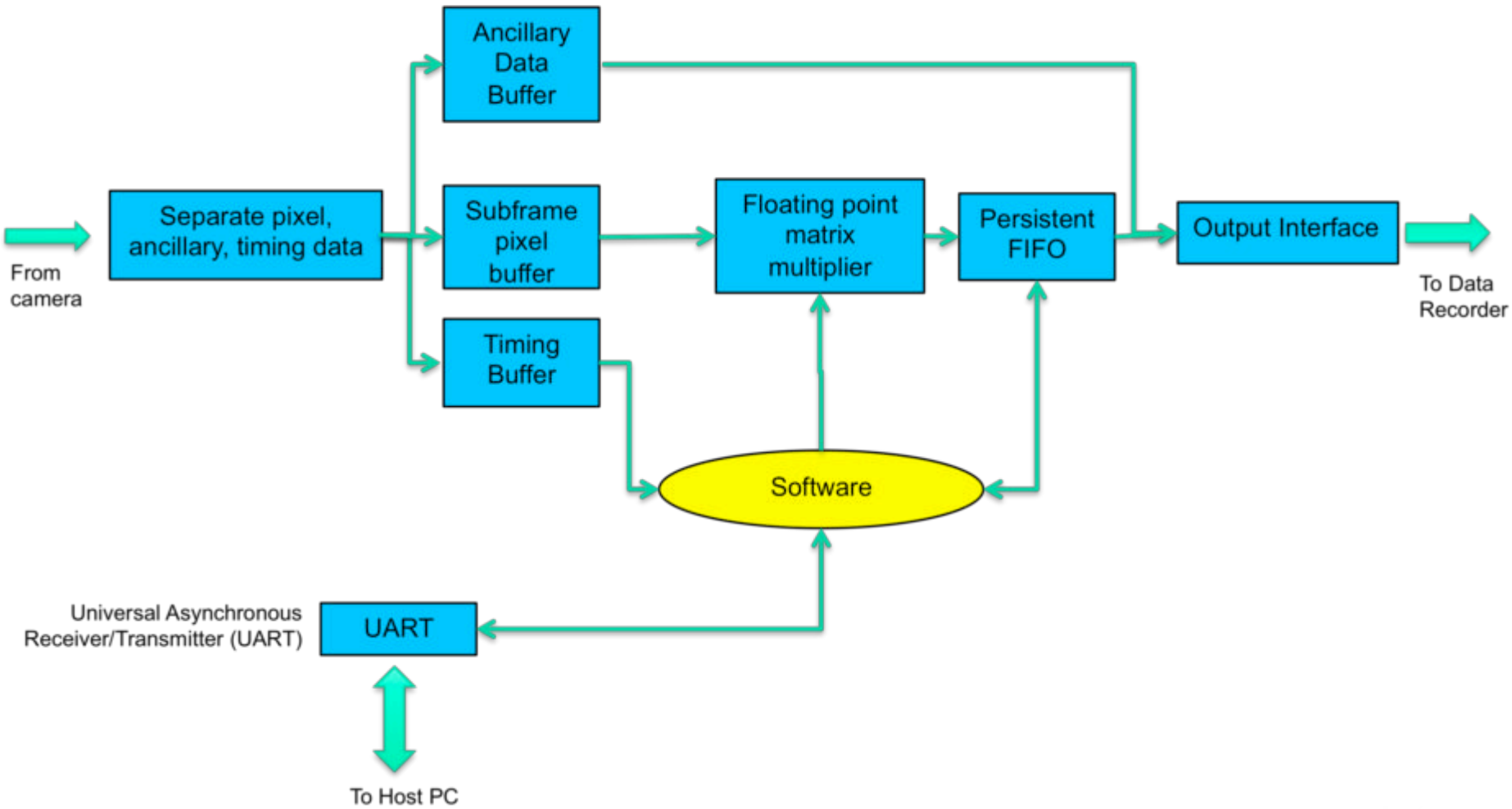
$$B^{\dagger} = \left(B^T B\right)^{-1} B^T$$

- Via a series expansion, each segment sees a linear combination
  - *I0 channel –* $\langle I, \nabla I, Q, \nabla Q \rangle$
  - *I45 channel –* $\langle I, \nabla I, U, \nabla U \rangle$
  - *I channel –* $\langle I, \nabla I \rangle$

$$\begin{pmatrix} I \\ \nabla I \\ Q \\ \nabla Q \end{pmatrix} = B^{\dagger} \begin{pmatrix} I_{0,1} \\ \vdots \\ I_{0,n} \end{pmatrix}$$

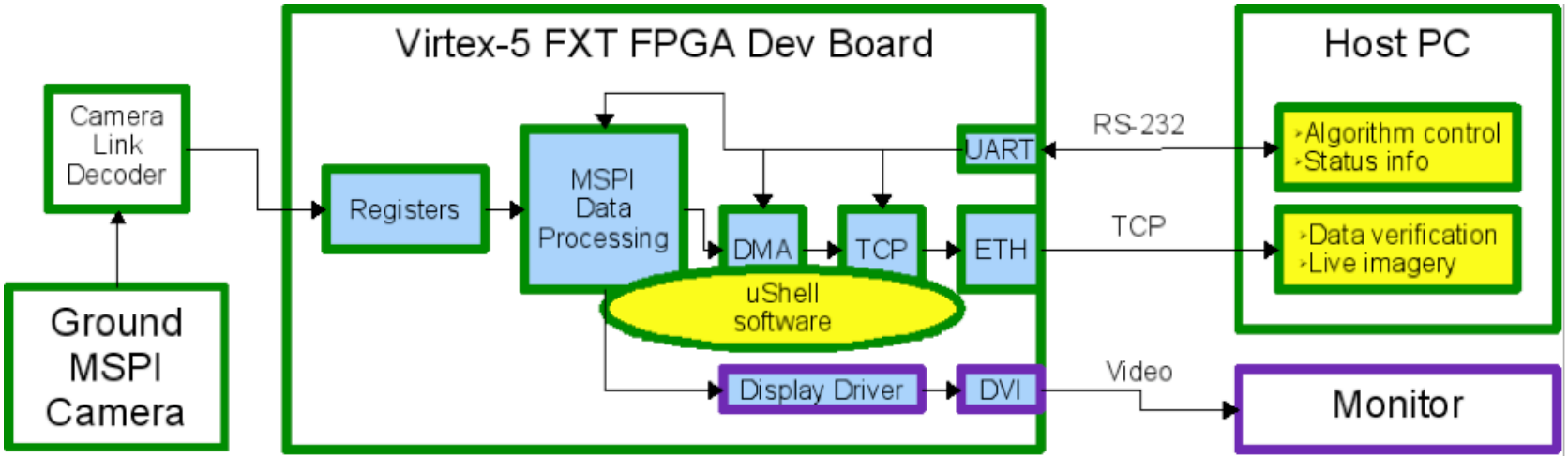
- Coefficients in the combination are analytic expressions (Bessel and trig functions) of the sample time and instrument parameters

MSPI On-Board Processing (OBP) Algorithm

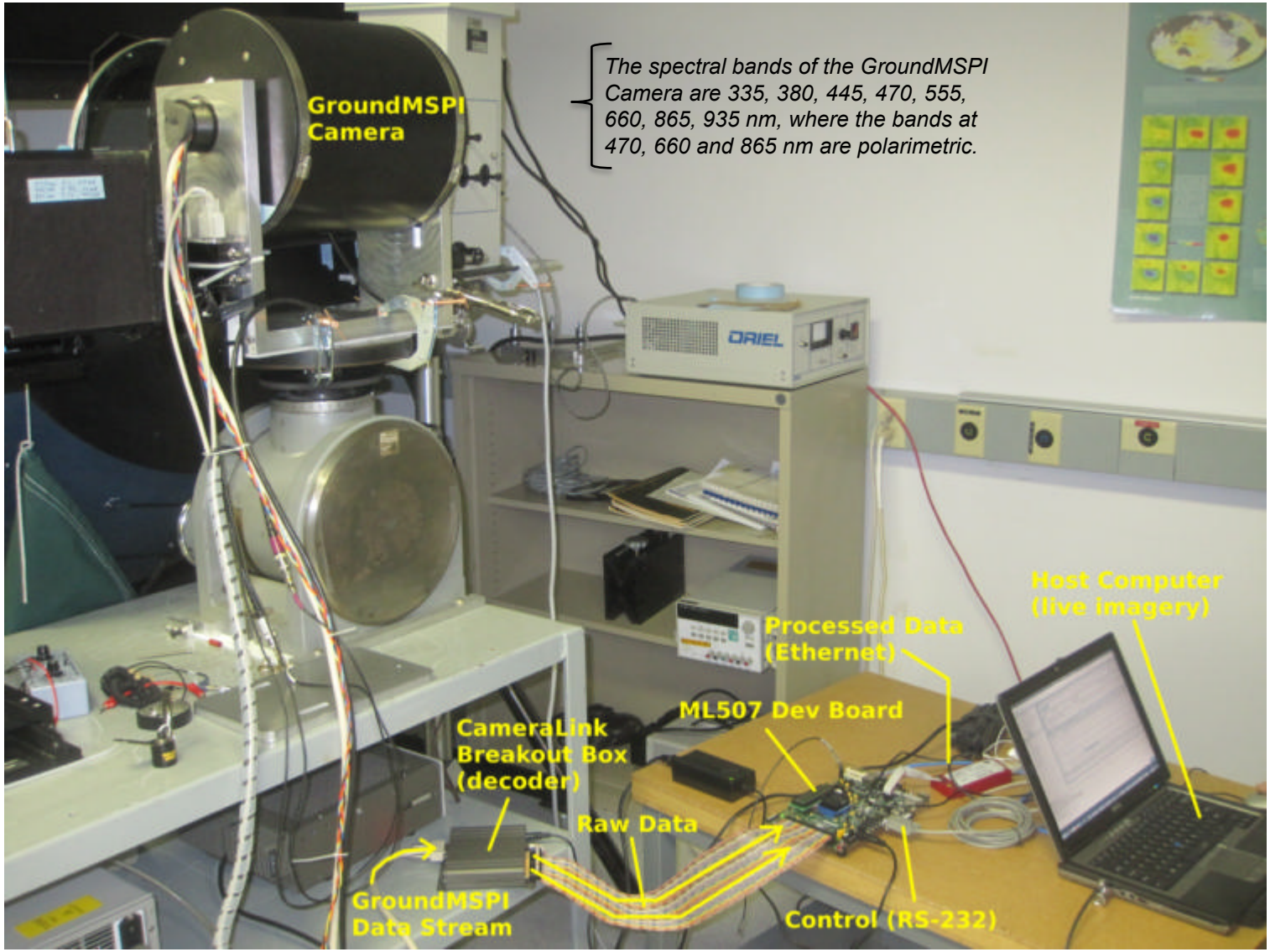


OBP Implementation on Virtex-5 FPGA

Component	Used	FX130T Total (% Utilized)	FX70T Total (% Utilized)
Occupied Slices	3,381	20,480 (16%)	11,200 (30%)
BlockRAM	25	298 (8%)	148 (17%)
DSP48	18	320 (5%)	128 (14%)
DCM_ADV	1	12 (8%)	12 (8%)
PLL_ADV	1	6 (16%)	6 (16%)

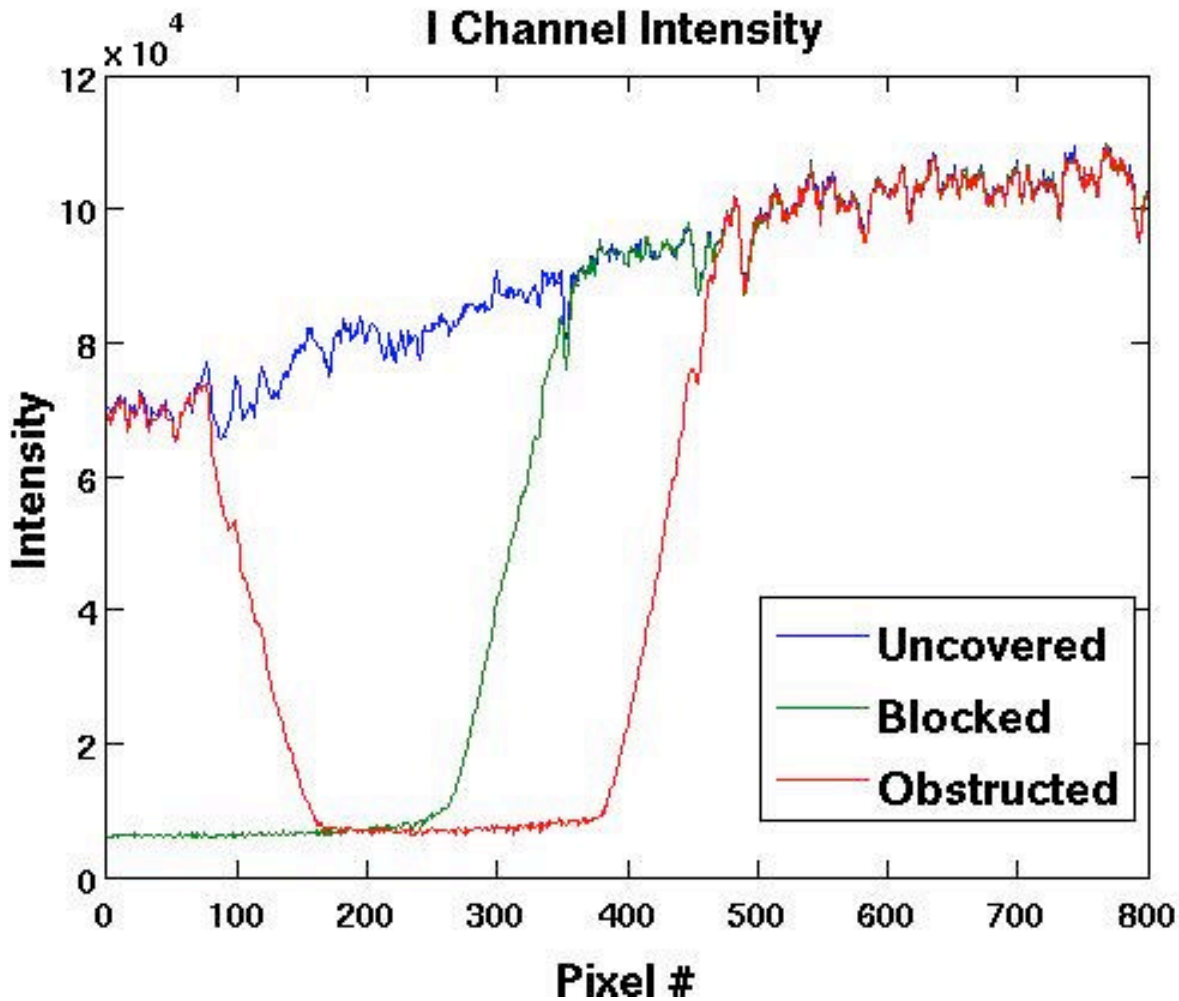


GroundMSPI Demo System



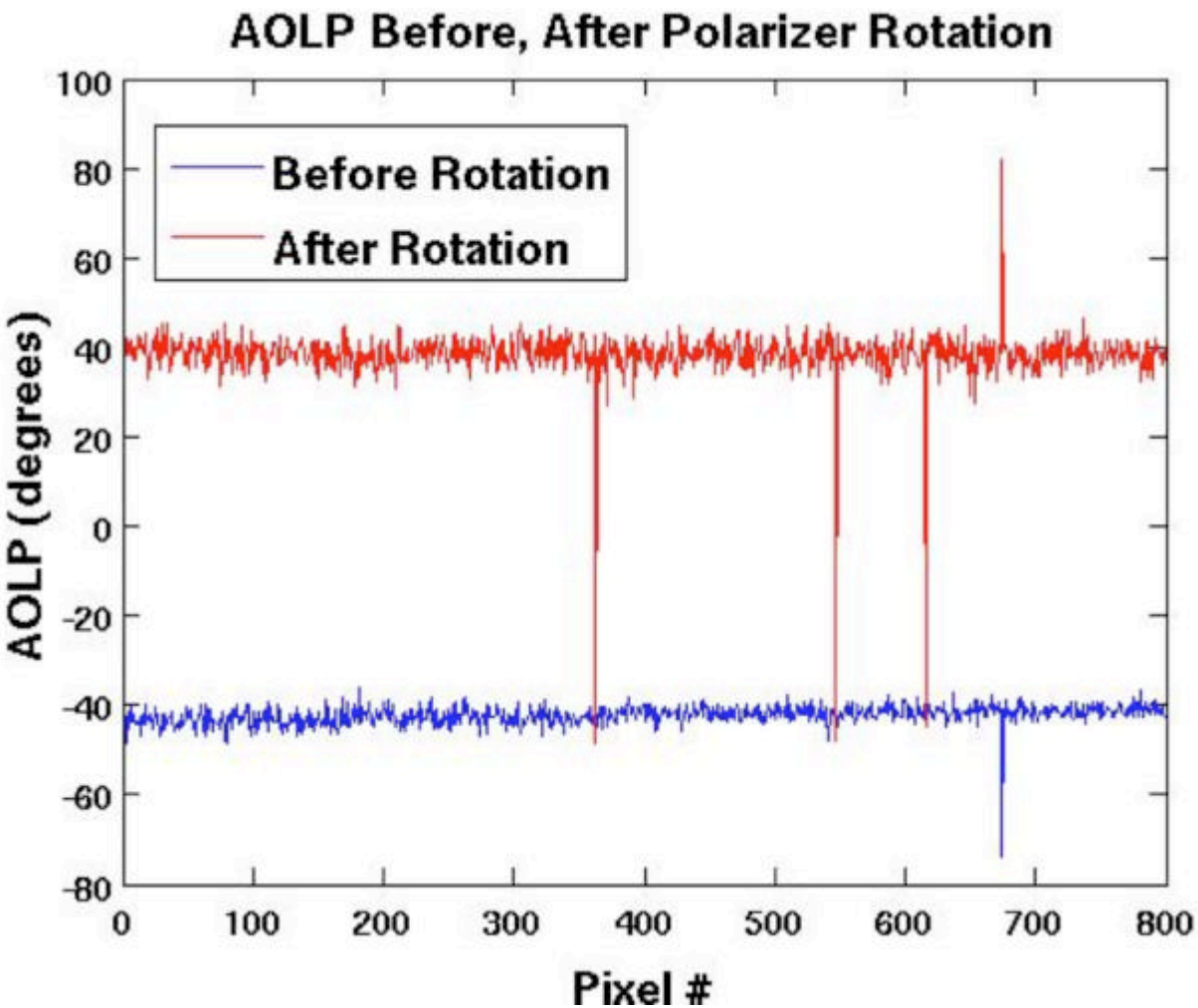
Experiment #1: Intensity Validation

OBJECTIVE: Cover a portion of the camera aperture to see the estimated Intensity, I, decrease.



Experiment #2: Angle of Linear Polarization, (AOLP) Validation

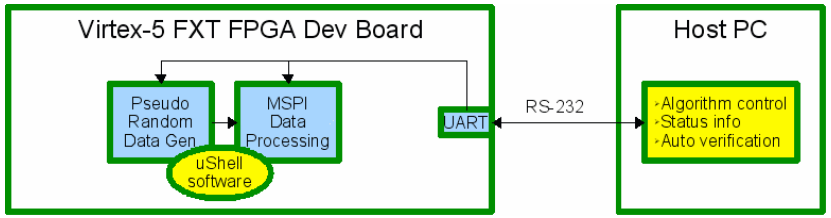
OBJECTIVE: Rotate a linear polarizer in front of the aperture to see the effect on estimated AOLP.



$$\mathrm{AOLP} = \frac{1}{2}\tan^{-1}(u/q)$$

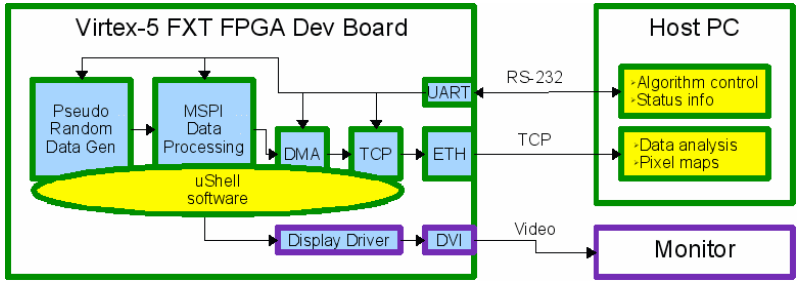
Progressive Demonstration Plan

1.



- Demonstrate MSPI data processing on pseudo-random data
- Auto verify results to known good values
- PC receives data / sends commands via UART
- STATUS: Complete (8/09)

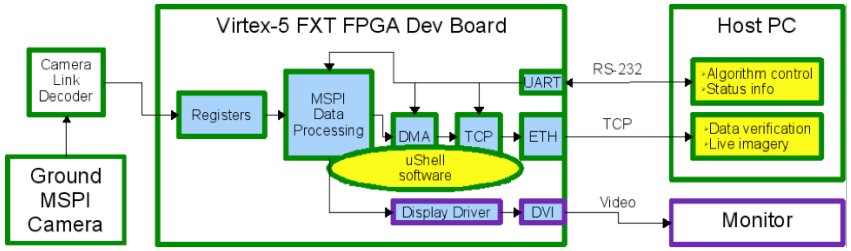
2.



- Add DMA and TCP/IP functionality in order to send real-time processed MSPI data to host for analysis
- Optional: live video feed directly to monitor
- STATUS: Complete (1/10)

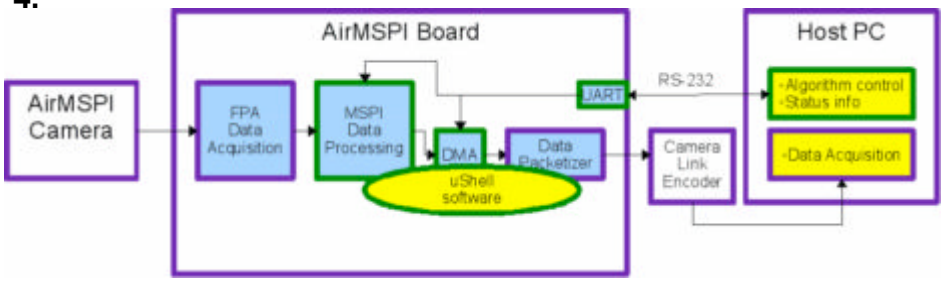
KEY
Blue: HW IP, Yellow: SW IP
Green outline: complete, Orange: work in progress, Purple: not started

3.



- Replace random generator with data formatter
- Grab raw data from Ground MSPI camera
- Send real-time processed MSPI data to host for analysis
- Optional: live video feed directly to monitor
- STATUS: Complete (5/10)

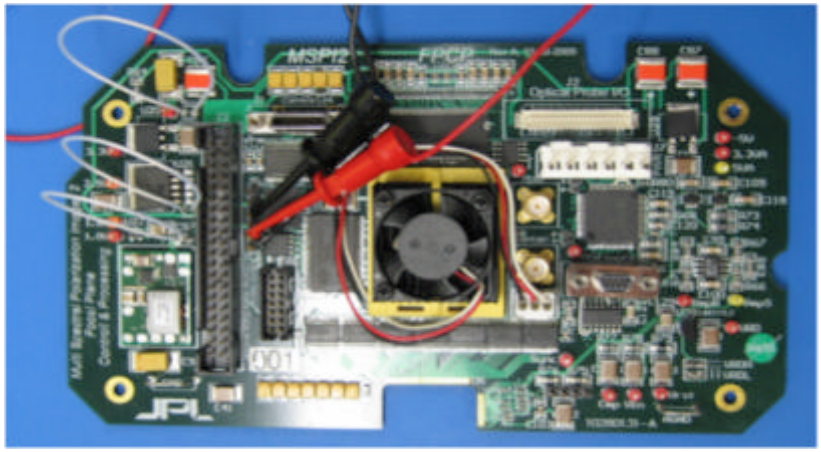
4.



- Move system to AirMSPI board
- Replace CameraLink front-end with FPA data acquisition
- Grab raw data from AirMSPI camera
- Send real-time processed MSPI data to host via off-board CameraLink encoder
- STATUS: Future Development (8/10)

Summary

- Real-Time On-Board Processing Validation of GroundMSPI Images via the Xilinx Virtex-5 FPGA algorithm has been demonstrated.
  - The least-squares fitting algorithm extracts intensity and polarimetric parameters in real-time, thereby substantially reducing the image data volume for spacecraft downlink without loss of science information.
  - The results of our two GroundMSPI validation experiments show that the OBP algorithm is processing image data correctly.
- Next we will integrate the OBP algorithm with the Xilinx Virtex-5 FPGA on the AirMSPI Focal Plane Control & Processing Board.



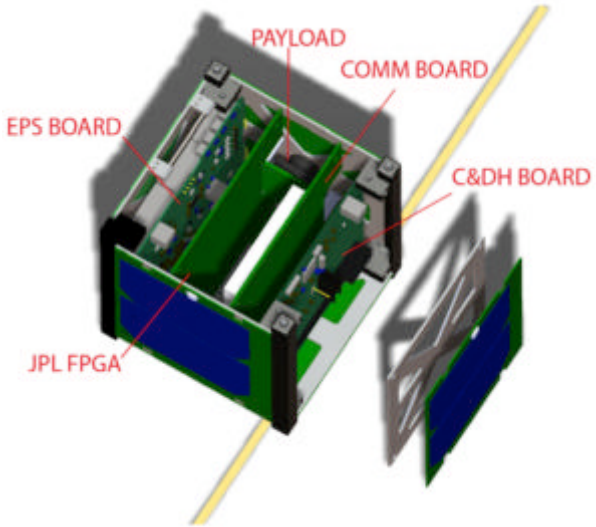
New Related ATI-QRS Task: COVE
CubeSat On-board processing Validation Experiment

Spaceborne validation (of polarimetry algorithm and Virtex-5 FPGA) at low cost.
ACE MSPI polarimetry algorithm implemented on the Xilinx Rad-Hard-By-Design (RHBD) Virtex-5 FPGA and integrated into the U. Michigan M-Cubed CubeSat for space validation

Approach

- Complete development of the U. Michigan 1U CubeSat with a 2.0 Megapixel CMOS camera chip sensor and integration of the JPL image processing payload.
- Manifest the flight on a NASA, or other, launch vehicle.
- Downlink on-board processing results and original image data for verification against ground tests.
- Validate total ionization dose radiation effects of the Virtex-5QV (XQR5VX130T) FPGA on orbit (Goal).

U. Michigan M-Cubed 1U CubeSat



KEY MILESTONES

• Engineering development units for JPL payload board and U. Michigan CubeSat complete	12/10
• M-Cubed flight unit completed and JPL Flight FPGA payload board integrated	06/11
• Flight unit testing, launch and operations ready, final report	09/11