Adapting the SpaceCube v2.0 Data Processing System for Mission-Unique Application Requirements

2015 AHS Conference
Montreal, Canada
June 16, 2015

Dave Petrick
Principal Engineer

SCIENCE DATA PROCESSING BRANCH
Code 587 • NASA GSFC
SpaceCube, Target Applications

- Small, light-weight, reconfigurable multi-processor platform for space flight applications demanding extreme processing capabilities
  - Reconfigurable components: FPGA, Software, Mechanical
  - Promote reuse between applications
- Hybrid Flight Computing: hardware acceleration of algorithms to enable onboard data processing and increased mission capabilities
- Example Applications: Instrument Data Interfacing and On-Board Processing, Autonomous Operations, Situational Awareness, Scalable Computing Architectures

### Hardware Algorithm Acceleration

<table>
<thead>
<tr>
<th>Application</th>
<th>Xilinx Device</th>
<th>Acceleration vs CPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAR</td>
<td>Virtex-4</td>
<td>79x vs PowerPC 405 (250MHz, 300 MIPS)</td>
</tr>
<tr>
<td>Altimeter</td>
<td>FX60</td>
<td></td>
</tr>
<tr>
<td>RNS GNFR</td>
<td>Virtex-4</td>
<td>25x vs PowerPC 405 (250MHz, 300 MIPS)</td>
</tr>
<tr>
<td>FPU, Edge</td>
<td>FX60</td>
<td></td>
</tr>
<tr>
<td>HHT</td>
<td>Virtex-1</td>
<td>3x vs Xeon Dual-Core (2.4GHz, 3000 MIPS)</td>
</tr>
<tr>
<td>EMD, Spline</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>Hyperspectral Data</td>
<td>Virtex-1</td>
<td>2x vs Xeon Dual-Core (2.4GHz, 3000 MIPS)</td>
</tr>
<tr>
<td>Compression</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>GOES-8 GndSys Sun correction</td>
<td>Virtex-1</td>
<td>6x vs Xeon Dual-Core (2.4GHz, 3000 MIPS)</td>
</tr>
<tr>
<td></td>
<td>300E</td>
<td></td>
</tr>
</tbody>
</table>

### Notes:
1. All functions involve processing large data sets (1MB+)
2. All timing includes moving data to/from FPGA
3. SpaceCube 2.0 is 4x to 20x more capable than these earlier systems

### On-Board Data Reduction

**On-board product generation yields factor of 165x data volume reduction**

Difference < 1%
“Fastest” consumer CPU in 2011
Space Processor Trend

MIPS


Shuttle  Galileo  HST  Pathfinder  ISS  EOS Terra  EOS Aqua  Mars Rovers  New Horizons  DAWN  LRO  MRO  SDO  GPM  Curiosity
Future Space Processing Requirement

Next Generation Mission Processing Requirements (Decadal Surveys)

Transistor count

Year


RCA 1802

RAD6000

RAD750

1,000x Gap

SCS750
SpaceCube Closes the Gap

Next Generation Mission Processing Requirements (Decadal Surveys)

Transistor count


SpaceCube v2.0
SpaceCube v1.0

1,000x Gap

SCS750

RAD750

RAD6000

RAD6000

1750A

RCA 1802
SpaceCube Family Overview

**v1.0**
- 2009: STS-125
- 2009: MISSE-7
- 2013: STP-H4
- 2016: STP-H5

**v1.5**
- 2012: SMART

**v2.0-EM**
- 2013: STP-H4
- 2016: STP-H5

**v2.0-FLT**
- 2015 GPS Demo
  - Robotic Servicing
  - Numerous proposals for Earth/Space/Helio
Example SpaceCube Processing

Real-Time Image Tracking of Hubble

Fire Classification

Gigabit Instrument Interfacing

Xilinx ISS Radiation Data

Spectrometer Data Reduction

Image Compression
On-Board Image Processing

- Successfully tracked Hubble position and orientation in real-time operations
- FPGA Algorithm Acceleration was required to meet 3Hz loop requirement

→ Typical space flight processors are 25-100x too slow for this application
SpaceCube v2.0 Flight System

Power Card
- 22-38V Input, 7A limit
- 5V/80W, 3.3V/53W, +/-12V/24W

Backplane Card
- 4 slots
- Point-to-Point
- Gigabit SERDES
- 2 processors, 1 I/O
- 3 processors

Chassis: 12.7 x 23 x 27 cm^3
Example Mission-Unique I/O Cards

- Video/Spacecraft Interface Card
- GPS RF Front-End Interface Card
- LIDAR High Speed Digitizer
- LIDAR Front-End Interface Card
Processor Card

- 2x Xilinx Virtex-5 (QV) FX130T FPGAs
- 1x Aeroflex CCGA FPGA
  - Xilinx Configuration, Watchdog, Timers
  - Auxiliary Command/Telemetry port
- 1x 128Mb PROM, contains initial Xilinx configuration files
- 1x 16MB SRAM, rad-hard with auto EDAC/scrub feature
- 4x 512MB DDR SDRAM
- 2x 4GB NAND Flash
- 16-channel Analog/Digital circuit for system health
- Optional 10/100 Ethernet interface
- Gigabit interfaces: 4x external, 2x on backplane
- 12x Full-Duplex dedicated differential channels
- 88 GPIO/LVDS channels directly to Xilinx FPGAs
- Mechanical support for heat sink options and stiffener for Xilinx devices

Power Draw: 10-15W
Weight: 0.98-lbs
22 Layers, Via-in-Pad
IPC 6012B Class 3/A
STP-H4 Operational on ISS

ISS SpaceCube Experiment 2.0 (ISE 2.0) on STP-H4

Next Up: STP-H5 in 2016
Adapting the SpaceCube Platform

1) SpaceCube-based Lidar
   – Goddard Reconfigurable Solid State Lidar (GRSSLi)

2) SpaceCube-based GPS
   – Based on NASA/GSFC Heritage “Navigator” Technology

3) ISS Robotic Avionics
   – Robotic Refueling Mission 3 (RRM3)
LiDAR Application (GRSSLi)

- Imaging LiDAR based on MEMS Scanning Mirror
- What can it do?
  - High quality & high rate proximity operations range imaging
    - 6mm range resolution, <1cm noise $1\sigma$, 5µs per pixel
    - Variable rate/ spatial resolution
      - 3Hz @ 256x256 pixels, 12Hz @128x128 pixels
    - Variable field of view, +/- 20° max (currently)
    - Variable fiber laser to extend dynamic range
      - <0.5m to 50 meter range max with 2µJ laser
  - Science quality sub-millimeter range resolution scans
    - Demonstrated 380µm resolution, 480µm noise $1\sigma$
    - Geophysical science
    - Model building and reconnaissance
  - Range finding
    - 182 meters demonstrated with 1 second average
- All capabilities listed do not require hardware modifications
  - Software configurable
SpaceCube-Based Lidar (GRSSLi)

- **Main Goal:** Forge Path to Flight
  - All designs spec flight parts (where possible)
  - TRL5 box built with engineering/commercial versions of flight parts
- **2 Box design**
  - Quickest path to working flight prototype
  - Allows separation of heavier and hotter MEB, putting just front end box (FEE) on optical bench.
  - Easier to modify for varying mission requirements (range/power, etc)
  - Allows easy integration of additional sensors like cameras, vision algorithms, or additional cards like GPS
GRSSLi System Integration

Main Electronics Box (SpaceCube v2.0)

Front End Box
GRSSLi Sub-millimeter Scans

Science LiDAR Requirements
- Range resolution: < 0.001 m
- Max Range: 10m
- Pixel Scale
  - 1cm Spatial Resolution @1m range

Demonstrated Capability
- Range resolution: 0.000380 m
- Range noise: 0.00480 m 1σ
- Laser Divergence: 2 mRad
  - At 1m: 4mm spot dia
  - At 10m: 4cm spot dia

3D Scan of “FeSS” Sandstone clearly exhibiting biologically derived textures

Mars Rock in Gale Crater with < 1 cm thick layers GRSSLi could measure the 3D arrangement of layered materials to understand depositional environments and textures associated with biosignature preservation potential.

Curiosity MastCam mosaic (100mm images, NASA/JPL/MSSS)
SpaceCube-Based GPS

Merges NASA GSFC SpaceCube avionics and “Navigator” technologies

NavCube with dual frequency RF card  Spirent GPS simulators
High Level
GPS RF Card Diagram
High Level GPS Processor Card Diagram

- PROM
- 422 Interfaces
- Ext Temp/Volt (3x available)
- J3
- J4
- Aeroflex
  - CFG
  - FSM
  - UART
  - ADC
  - Ser Sync
  - Clock/Resets
- Xilinx 0
  - Unused FPGA Resources
  - C&DH
- Xilinx 1
  - GPS Embedded System
- Flash/DDR/SRAM
- DDR
- J2
- GPS RF Signals
- X0 CFG
- X0/X1 CFG
- SerSync
- WDT
- S/C TLM
- Debug
- X1 CFG
- X1/X0 CFG
- SerSync
- WDT
- Debug

SCIENCE DATA PROCESSING BRANCH • Code 587 • NASA GSFC
SpaceCube GPS Tracking Data

Tracking GPS L1 and L2C signals

- CN0 - GPS L1 signals
- CN0 - GPS L2C signals

L1 measurements – L2 measurements
MMS Mission On-Orbit Performance of GPS Navigator

Nsv: number of GPS satellites tracked

Radial pos: radial distance from center of Earth
Robotic Refueling Mission (RRM)
SpaceCube on the ISS

ISS Flying Towards You

Image Credit: DoD Space Test Program
Enabling Satellite Servicing

10x Realtime
Questions?