Advanced Hybrid On-Board Science Data Processor - SpaceCube 2.0

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On-Board Data Processing
For ESDS Era Missions

On-Board Processing
• Data Volume Reduction
• Image Processing
• Autonomous Operations
• Product Generation
• Event / Feature Detection
• Real-time / Direct Broadcast
• Docking / Servicing
• Compression
• Calibration / Correction
• Classification
• Inter-platform collaboration

Hybrid Science Data Processing
• CPU
• FPGA
• DSP

GSFC SpaceCube On-Board Processor
• 10x-100x computing performance
• Lower power (MIPS/watt)
• Lower cost (commercial parts)
• Radiation tolerant (not hardened)
• Software upset mitigation
<table>
<thead>
<tr>
<th>Unit</th>
<th>Mission</th>
<th>Notes</th>
<th>Specs</th>
<th>Stats</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>SpaceCube 1.0a</td>
<td>Hubble Servicing Mission 4</td>
<td>Relative Navigation Sensors Experiment STS-125 May 2009</td>
<td>4”x4” card (2) Virtex4</td>
<td>Size: 5”x5”x7” Wt: 7.5 lbs Pwr: 37W</td>
<td>2009 Flight</td>
</tr>
<tr>
<td>SpaceCube 1.0b</td>
<td>MISSE-7 (ISS)</td>
<td>added RS-485, RHBS, STS-129 Nov 2009</td>
<td>4”x4” card (2) Virtex4</td>
<td>Size: 5”x5”x7” Wt: 7.5 lbs Pwr: 32W</td>
<td>In Flight</td>
</tr>
<tr>
<td>SpaceCube 1.0c</td>
<td>DEXTRE Pointing Package (ISS)</td>
<td>Original RNS unit, w/added 1553 &amp; Ethernet</td>
<td>4”x4” card (2) Virtex4</td>
<td>Size: 5”x5”x7” Wt: 7.5 lbs Pwr: 40W</td>
<td>Final stages of Implementation</td>
</tr>
<tr>
<td>SpaceCube 1.5</td>
<td>SMART (DoD/ORS)</td>
<td>adds GigE &amp; SATA, commercial parts, sounding rocket flight</td>
<td>4”x4” card (1) Virtex5</td>
<td>Size: 5”x5”x4” Wt: 4 lbs Pwr: &lt; 20W</td>
<td>Under Development</td>
</tr>
<tr>
<td>SpaceCube 2.0</td>
<td>Earth/Space Science Exploration missions</td>
<td>Std 3U form factor, GigE, SATA, Spacewire, cPCI</td>
<td>4”x6” card (2) Virtex5 (1) SIRF</td>
<td>Size: 5”x5”x7” Wt: &lt; 10 lbs Pwr: 20-40W</td>
<td>Under Development</td>
</tr>
<tr>
<td>SpaceCube 2.0 Mini</td>
<td>CubeSats, Sounding Rocket, UAV</td>
<td>“Mini” version of SpaceCube 2.0, CubeSat form factor</td>
<td>2.5”x2.5” card (1) Virtex5/SIRF</td>
<td>Size: 3.5”x3.5”x3.5” Wt: 3 lbs Pwr: &lt;10W</td>
<td>Under Development</td>
</tr>
</tbody>
</table>
### Processor Comparison

<table>
<thead>
<tr>
<th>Processor</th>
<th>MIPS</th>
<th>Power</th>
<th>MIPS/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIL-STD-1750A</td>
<td>3</td>
<td>15W</td>
<td>0.2</td>
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<tr>
<td>RAD6000</td>
<td>35</td>
<td>10-20W</td>
<td>2.33¹</td>
</tr>
<tr>
<td>RAD750</td>
<td>300</td>
<td>10-20W</td>
<td>20²</td>
</tr>
<tr>
<td>SPARC V8</td>
<td>86</td>
<td>1W³</td>
<td>86³</td>
</tr>
<tr>
<td>LEON 3FT</td>
<td>60</td>
<td>3-5W³</td>
<td>15³</td>
</tr>
<tr>
<td>GSFC SpaceCube 1.0</td>
<td>3000</td>
<td>5-15W</td>
<td>400⁴</td>
</tr>
<tr>
<td>GSFC SpaceCube 2.0</td>
<td>5000</td>
<td>10-20W</td>
<td>500⁵</td>
</tr>
</tbody>
</table>

**Notes:**

1 – typical, 35 MIPS at 15 watts
2 – typical, 300 MIPS at 15 watts
3 – processor device only ... total board power TBD
4 – 3000 MIPS at 7.5 watts (measured)
5 – 5000 MIPS at 10 watts (calculated)
Current SpaceCube Systems

- SpaceCube 1.0a
- Prototype
- SpaceCube 1.5
- SpaceCube 1.0b
On-Board Image Processing

HST-SM4

GSFC SpaceCube 1.0a - Hubble SM 4 (May 2009):
• Autonomous Rendezvous and Docking Experiment
• Hosted camera AGC and two Pose algorithms

GSFC SpaceCube 1.0a - Hubble SM 4 (May 2009):
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STS-125 Payload Bay

Long Range Camera on Rendezvous

Short Range Camera on Deploy

Flight Image

RNS Tracking Solution

Flight Image

RNS Tracking Solution
GSFC SpaceCube 1.0b (Nov 2009):
• “Radiation Hardened by Software” Experiment (RHBS)
• Autonomous Landing Application
• Collaboration with NRL

Software Upset Mitigation

MISSE7

Orbit: ISS
Days Up: 550+
Total SEUs: 100+
Total Errors: 0
Small Rocket/Spacecraft Technologies (SMART)

- Joint program between NASA and DoD Operationally Responsive Space (ORS)
- Develop faster, leaner, and more efficient approach to space flight
- SpaceCube 1.5 serves as multi-function avionics
- Ingest RocketCam, GigE camera, and sensor data
- On-board storage to SATA drives
- Downlink to ground through transponder
Special Purpose Dexterous Manipulator (DEXTRE)

- Installed on ISS 2008
- Two 7-jointed arms
- Body roll joint that allows swiveling of its torso

Dextre Pointing Package (DPP)

- Support interchangeable science payloads
- Enable payload
  - Precise pointing
  - Real-time telemetry
  - Data storage
On-Board Data Reduction

Accomplishments

SAR Nadir Altimetry Results (FY07)

On-board processing yields lossless 6:1 data volume reduction

Difference < 0.1%
On-Board Data Reduction (cont)

Accomplishments

SAR Mapping Results (FY09)

Original Matlab Output

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

SpaceCube Output

Difference < 1%
On-Board Product Generation

- Classification
- Product Generation
- Event Detection
- Atmospheric Correction
HyspIRI Demonstration Testbed

HyspIRI SpaceCube IPM Testbed

VSWIR Simulator

TIR Simulator

4 x 440 MHz PPC
1GByte RAM
Rocket I/O
10 GByte SSR

SpaceCube 2.0 Development System

X-Band D/L Simulator

Cloud Classifier
SpaceCube 2.0 Block Diagram

- Power Card
- SpaceCube2 Processor Card
- FLASH Memory Card
- Mission Unique I/O

Ports:
- Spacewire / LVDS / MGT / GigE / Mission Unique High-speed

Standard 3U Card Form Factor
Nominal Box Level Parameters:
- Size 5”x5”x7”, Weight 10-15 lbs, Power 10-20 watts
SpaceCube 2.0 Processor Card

3U Compact PCI Card

Std J1
cPCI
32-bit

Custom J2
serial
gigabit,
Spacewire,
analog, and
GPIO

V5FX130T
PPC440
512MB RAM
2GB FLASH
PPC440
512MB RAM
2GB FLASH

V5FX130T
PPC440
512MB RAM
2GB FLASH
PPC440
512MB RAM
2GB FLASH

V5 SIRF
8MB rad-hard SRAM, a 64Mb PROM,
8 GB Flash, 512MB SDRAM

SpaceWire
LVDS/RS-422
Ethernet
MGT
Special Command Reset
UART
JTAG

GODDARD SPACE FLIGHT CENTER
SpaceCube 2.0

4X ELECTRICAL CONNECTORS

4X CARD SLOTS
SpaceCube “Mini”
CubeSats: IPEX & TechCube 1
STP-H4 / ISE 2.0 Location & FOV

ISS Flying Towards You

MISSE-7 & MISSE-8
SpaceCube 1.0b
ELC-2

Zenith

Columbus-EPF

Nadir

ELC-3

#1

#2

JEM-EF

STP-H4/ISE 2.0
ELC-1
Launch Feb 13
Nadir/Ram/Outboard
ExPA Location

Image Credit: DoD Space Test Program
ISS SpaceCube Experiment 2.0 (ISE 2.0)

Payload Image Credit: DoD Space Test Program
Questions?

tom.flatley@nasa.gov

http://en.wikipedia.org/wiki/SpaceCube

http://gsfctechnology.gsfc.nasa.gov/SpaceCube.htm