SpaceCube Technology Brief
Hybrid Data Processing System

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SpaceCube Overview

Heritage
- GOAL: close the gap with commercial processors while retaining reliability
- Started in 2006 at GSFC as R&D
- 38+ Xilinx device-years on orbit
- 22 Xilinxes in space by 2016
- 8 systems in space by 2016
- Various R&D efforts on hardware acceleration

Hybrid Data Processing
- Parallel data processing:
  - FPGA + DSP + Processor(s)
- SpaceCube can move 3,000x more data than a sequential processor per clock cycle

SpaceCube v2.0
- Currently TRL-7
- Leverages 10 years of design heritage and operation experience
- $10M+ of NRE
- Adopted by SSCO for all missions
- IPC 6012B Class 3/A PWB Reliability
- Modular: 9 Mission-Unique I/O cards
- Run-Time Reconfigurable

Xilinx Virtex-5 FPGA

SpaceCube v2.0

SpaceCube is a Mission-Enabling Technology
Commercial Processor Trend

“Fastest” consumer CPU in 2011
Space Processor Trend
Processor Trend Comparison

[Graph showing the comparison of processor trends from 1975 to 2015, with various processors and their MIPS values indicated along the timeline.]
Future Space Processing Requirement

Next Generation Mission Processing Requirements (Decadal Surveys)
SpaceCube Closes the Gap

Next Generation Mission Processing Requirements (Decadal Surveys)
SpaceCube Family Overview

**v1.0**
- 2012  SMART (ORS)

**v1.5**
- 2013  STP-H4
- 2016  STP-H5

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

**v2.0-FLT**
- 2017  RRM3
- 2018  STP-H6 (NavCube)
- 2018  NEODaC
- 2020  Restore-L
- Many NASA proposals

**v2.0 Mini**
- 2009  STS-125
- 2009  MISSE-7
- 2013  STP-H4
- 2016  STP-H5
- 2018  STP-H6
- 2016  STP-H5
- Many NASA proposals
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

Rendezvous

Deploy (Docking Ring)

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

- Restore-L/RRM3/NEODaC Computer
- SpaceCube Processor Card
- SpaceCube Backplane Card
- SpaceCube Power Card
Processor Card

Power Draw: 6-15W
Weight: 0.98-lbs
22 Layers, Via-in-Pad
IPC 6012B Class 3/A

- 2x Xilinx Virtex-5 (QR) 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 pipes and stiffener for Xilinx devices

2014 Global Award: Most innovative design worldwide in the Military/Aerospace sector
Example Mission-Unique I/O Cards

- Restore-L Video/Spacecraft Interface Card
- GPS RF Front-End Interface Card
- LIDAR Digitizer, Front-End, and Laser Card
Spinoff Technologies

GPS Receiver – L1/L2C Tracking

LIDAR Instrument – Configurable Resolution
High Level Requirements:
- Interface with Spacecraft and Payload Busses
- Interface with vision sensors
- Host Relative Proximity Operations application
- Host Robotic Manipulation Control application

Restore-L will fly 21 Xilinx Virtex-5 FPGAs
What About Radiation Effects??

**Restore-L SpaceCube Data Processing Architecture**

If Spare is “Cold”, then worst case error probability: $Pe(sys) = [8 \times Pe(Xilinx) + 16 \times Pe(DDR)]$
Establishing SEE Error Rates

**Assessment Process**

1. Radiation Environment
2. Establish Device WCA
3. Establish System WCA
4. Establish Application WCA
5. ID Functional Independence
6. Selective FPGA Mitigation

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### NASA Risk Assessment

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Safety</th>
<th>Technical</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Estimated likeli</td>
<td>Estimated likeli</td>
</tr>
<tr>
<td></td>
<td>of event occurre</td>
<td>of not meeting perfo</td>
</tr>
<tr>
<td></td>
<td>nce</td>
<td>rm requirements</td>
</tr>
<tr>
<td>5 Very High</td>
<td>(P_{SE} &gt; 10^{-1})</td>
<td>(P_T &gt; 50%)</td>
</tr>
<tr>
<td>4 High</td>
<td>(10^{-2} &lt; P_{SE} \leq 10^{-1})</td>
<td>(25% &lt; P_T \leq 50%)</td>
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<tr>
<td>3 Moderate</td>
<td>(10^{-3} &lt; P_{SE} \leq 10^{-2})</td>
<td>(15% &lt; P_T \leq 25%)</td>
</tr>
<tr>
<td>2 Low</td>
<td>(10^{-5} &lt; P_{SE} \leq 10^{-3})</td>
<td>(2% &lt; P_T \leq 15%)</td>
</tr>
<tr>
<td>1 Very Low</td>
<td>(10^{-6} &lt; P_{SE} \leq 10^{-5})</td>
<td>(0.1% &lt; P_T \leq 2%)</td>
</tr>
</tbody>
</table>

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### Mode and Utilization

<table>
<thead>
<tr>
<th>Mode</th>
<th>Time (s)</th>
<th>Device WCA</th>
<th>PCC WCA</th>
<th>RPO PCC</th>
<th>RSW PCC</th>
<th>RPO + RSW</th>
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<tbody>
<tr>
<td>one orbit (96 minutes)</td>
<td>5760</td>
<td>0.484%</td>
<td>1.934%</td>
<td>1.074%</td>
<td>0.222%</td>
<td>1.296%</td>
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<tr>
<td>Rendezvous (30 min)</td>
<td>1800</td>
<td>0.151%</td>
<td>0.604%</td>
<td>0.336%</td>
<td>0.069%</td>
<td>0.405%</td>
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<tr>
<td>Capture (77 sec)</td>
<td>77</td>
<td>0.006%</td>
<td>0.026%</td>
<td>0.014%</td>
<td>0.003%</td>
<td>0.017%</td>
</tr>
</tbody>
</table>

Note: assumes BRAM Mitigation

Note: Actual utilization for RPO and RSW PCCs as of 4/18/2016

Note: assumes RPO & RSW PCCs must be error-free for full operation
Robotic Refueling Mission SpaceCube

High Level Requirements:
• Interface with ISS and RRM3 instruments:
  • Cameras, thermal imager, motors
• Monitor/Control cryocooler and fuel transfer
• Stream video data
• Motor control of robotic tools
• Host Wireless Access Point
NEODaC Instrument Development

- Detect and Characterize NEOs
- Working with “Partner” organization on complex detector instrument
- SpaceCube FPGAs being used to solve very challenging avionics requirements and host on-board data processing applications and compression
- Successful Detector readout with SpaceCube completed
- March 2018 Delivery

<table>
<thead>
<tr>
<th>Transmitter Swing (mV)</th>
<th>Transmitter % Pre-emphasis</th>
<th>Test Duration</th>
<th>Bit Error Count</th>
<th>BER (*)</th>
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<tbody>
<tr>
<td>500</td>
<td>0</td>
<td>6hr</td>
<td>32</td>
<td>9.2E-13</td>
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<tr>
<td>500</td>
<td>8</td>
<td>18hr</td>
<td>0</td>
<td>9.6E-15</td>
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<tr>
<td>800</td>
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<td>20hr</td>
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<tr>
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<td>17</td>
<td>20hr</td>
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<td>8.7E-15</td>
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<tr>
<td>1300</td>
<td>0</td>
<td>19hr</td>
<td>52</td>
<td>4.7E-13</td>
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</table>

Note: BER calculation assumes at least 1 error
- 58-hours of error-free transmission
SpaceCube on the ISS

ISS Flying Towards You

Image Credit: DoD Space Test Program
STSC-125 Shuttle Payload Bay

• 7 years of operation
• 4x Virtex-4 XC4VFX60: 0.1 SEU/FPGA/Week
• 2x on-orbit file uploads and reconfiguration

SpaceCube v1.0

MISSE-7/8 ISS Payload
STP-H4 ISS Payload

2 years of operation. 3x Virtex-5 XC5VFX130T: 1 SEU/FPGA/Week
Successful on-orbit file upload and reconfiguration
The Space Test Program-H5 (STP-H5) external payload, a complement of 13 unique experiments from seven government agencies, is integrated and flown under the management and direction of the Department of Defense’s Space Test Program.

SpaceX Launch Scheduled November 11, 2016
Questions?