



NASA GSFC Avionics Architectures and Future Directions

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Acronym List

AI	Artificial Intelligence	GSFC	Goddard Space Flight Center
C&DH	Command and Data Handling	HPSC	High Performance Spaceflight Computing
CAN	Controller Area Network	ICESAT-2	Ice, Cloud, and land Elevation Satellite 2
cFE	Core Flight Executive	I2C	Inter-Integrated Circuit
cFS	Core Flight System	IP	Intellectual Property
cPCI	Compact Peripheral Component Interconnect	MUSTANG	Modular Unified Space Technology Avionics for Next Generation
COTS	Commercial Off the Shelf	NASA	National Aeronautics and Space Administration
DET	Direct Energy Transfer	OSAL	Operating System Abstraction Layer
DSP	Digital Signal Processing	POL	Point Of Load
EMI	Electromagnetic Interference	PSE	Power System Electronics
EMC	Electromagnetic Compatibility	PSP	Platform Support Package
EO-1	Earth Observing 1	RF	Radio Frequency
FPGA	Field Programmable Gate Array	RMAP	Remote Memory Access Protocol
GEDI	Global Ecosystem Dynamics Investigation	RRM3	Remote Refueling Mission 3
GHz	Gigahertz	SAR	Synthetic Aperture Radar
GMSA	Goddard Modular Smallsat Architecture	SCEB	Smallsat Common Electronics Board
GPS	Global Positioning System	SPI	Serial Peripheral Interface
GPU	Graphics Processing Unit	SRIO	Serial RapidIO
GN&C	Guidance Navigation and Control	UART	Universal Asynchronous Receiver/Transmitter



Outline

- **NASA GSFC Overview**
- **Avionics Scope**
- **Current GSFC Avionics Architectures**
- **Future Requirements Drivers**
- **How Future Architectures Can Meet These Needs**
- **Current Challenges**



NASA GSFC Overview

- **NASA's first Space Flight Center (established 1959)**
- **Largest Collection of Scientists & Engineers in the U.S.**
- **Nearly 300 successful missions including the World's First Weather Satellite and the Hubble Space Telescope**
- **2006 Nobel Prize in Physics [Big Bang/Cosmic Background]**
- **Hubble Space Telescope Supported 2011 Nobel Prize in Physics**

=> *We TRANSFORM Human Understanding of Earth and Space*

Facilities

- GSFC Greenbelt, MD
- GSFC Wallops Flight Facility, VA
- IV&V Facility, WV
- Goddard Institute for Space Studies, NY
- Ground Stations at White Sands Complex, NM





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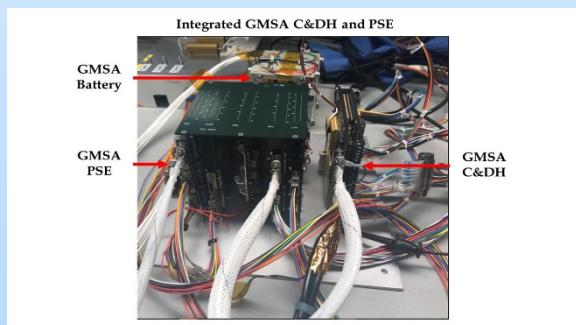
Avionics Scope

- **The scope of avionics can vary widely across organizations**
- **For the purposes of this presentation, the scope of avionics is considered to include:**
 - **Command and Data Handling (C&DH)**
 - **Power System Electronics (PSE)**
 - **Guidance Navigation and Control (GN&C)**
 - **Uplink/downlink (but not the full transponder)**
 - **Onboard Networks**
- **Avionics scope does not include science instruments**
 - **However, avionics components often are used within instrument electronics**

Current GSFC Avionics Architectures

- **GSFC uses multiple hardware architectures to implement avionics, each targeted for different use cases**

Architecture	Purpose
MUSTANG (Modular Unified Space Technology Avionics for Next Generation)	Command & Data Handling (C&DH) and Power System Electronics (PSE) for medium to large missions
GMSA (Goddard Modular Smallsat Architecture)	Command & Data Handling (C&DH) and Power System Electronics (PSE) for cubesats and smallsats
SpaceCube	High performance onboard processing applications



Integrated GMSA PSE and C&DH



Global Ecosystem Dynamics Investigation (GEDI) MUSTANG



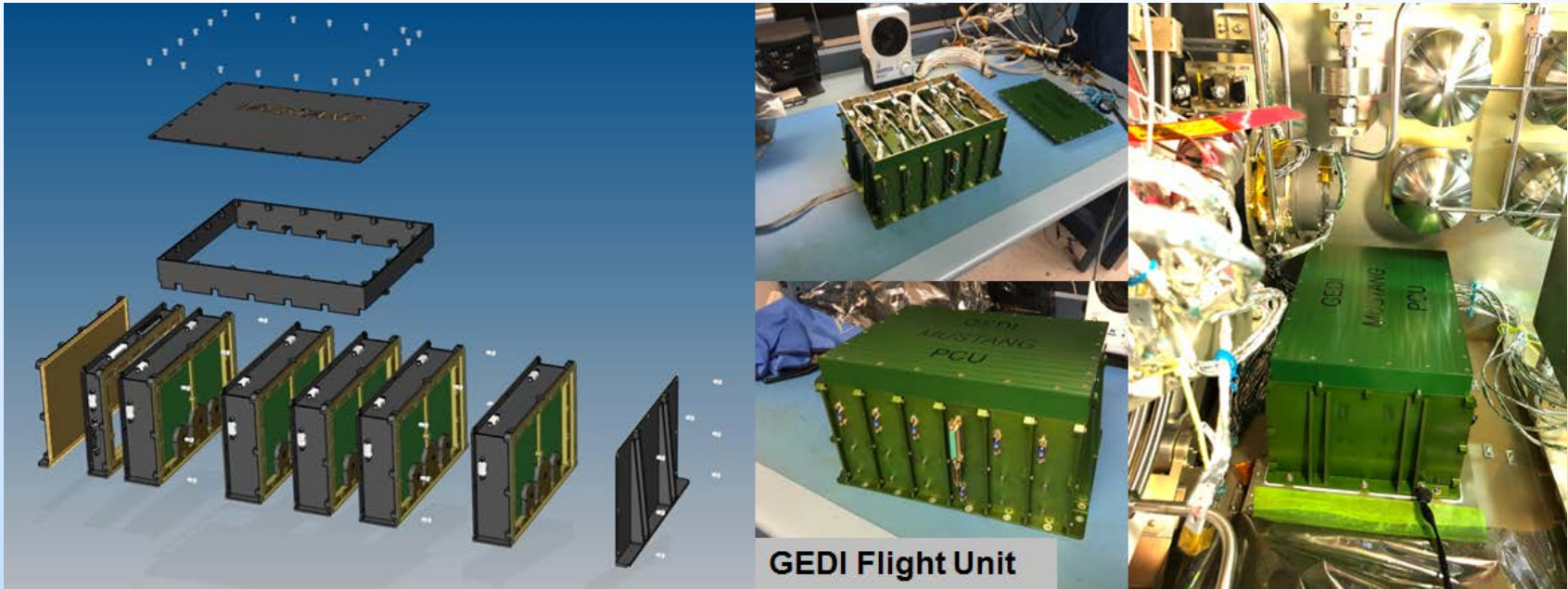
Robotic Refueling Mission 3 (RRM3) SpaceCube



MUSTANG

- **Derived from avionics flown on recent flight missions, MUSTANG targets medium to large missions and instruments**
- **Employs slice-based architecture, providing a suite of electronic modules that can implement spacecraft avionics and instrument electronics**
- **Packaging concept has flexibility to accommodate varying slice widths and both single and multi-box configurations**
- **Uses a dual core GR712C as the primary processor**
- **Also uses a LEON3FT soft-core processor embedded within an RTG4 FPGA as an auxiliary processor**
- **Uses SpaceWire/RMAP (Remote Memory Access Protocol) for internal and external communication**

MUSTANG



GEDI Flight Unit

MUSTANG Architecture

- Some existing hardware

**Engine
Valve Driver
Card**



**Housekeeping
Card**



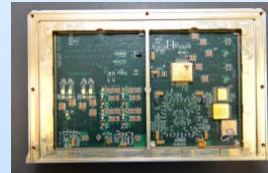
**Digital IO
Card**



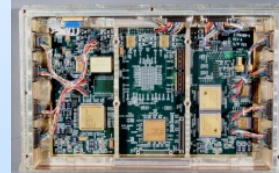
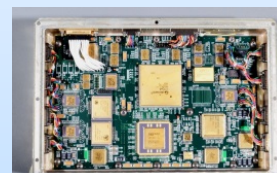
**Communication
Card**



**PSE
Monitor
Card**



**Processor
Card**



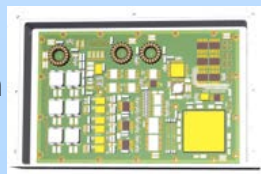
**Output
Module
Card**



**Deployment
Card**



**Mechanism
Control
Card**

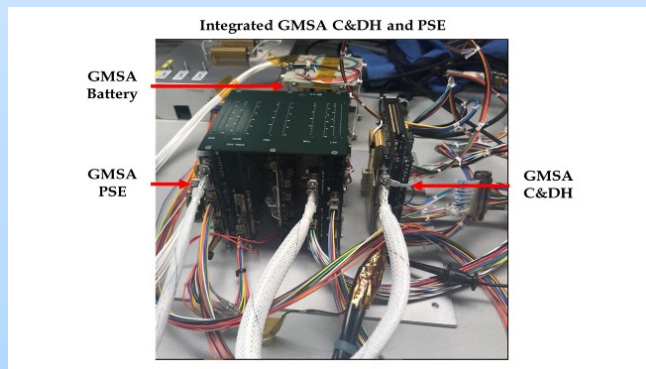


**Data Storage
Card (Not Fully
Populated) Full
Capacity 3.5Tb**



GMSA

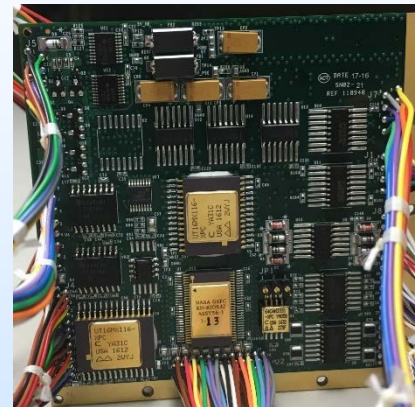
- **GMSA targets smallsat and cubesat missions that must operate reliably for long durations in harsh radiation environments**
- **The GSMA C&DH consists of a Smallsat Common Electronics Board (SCEB) and a mission specific adapter card interconnected via stacking connectors**
- **The SCEB implements the flight processor as a soft core LEON3FT within a reprogrammable FPGA**
- **The SCEB also provides UART, I2C, SPI, CAN, and SpaceWire interfaces**
- **The GSMA PSE consists of 5 cards interconnected via a backplane and uses Direct Energy Transfer (DET) and can support both 3-axis and spin-stabilized spacecraft**



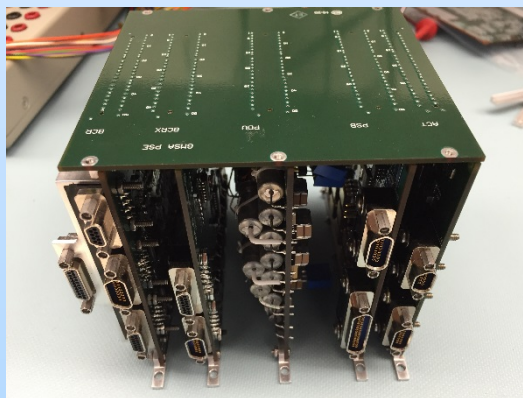
- Existing hardware



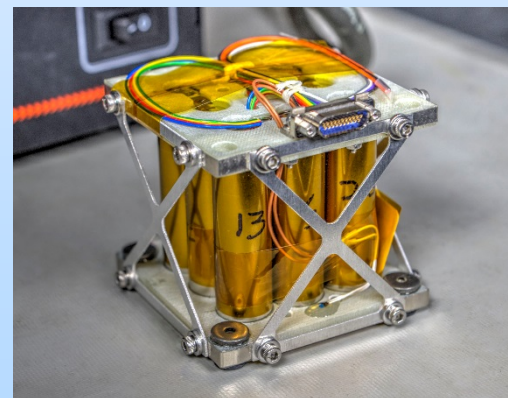
SCEB



Adapter Board



PSE



Battery Assembly

SpaceCube

- SpaceCube is a high performance reconfigurable science/mission data processor based on Xilinx Virtex FPGAs (Field Programmable Gate Arrays)
- The current SpaceCube version 2.0 processor is based on the Virtex-5 FPGA and is implemented as a 3U cPCI board
- Mission specific SpaceCube implementations consist of a processor board along with necessary I/O boards
- SpaceCube allows hybrid processing within the FPGAs
 - Embedded processor cores
 - DSP (Digital Signal Processing) function blocks
 - FPGA logic
- Radiation upset mitigation techniques are employed, including the use of a small “critical function” manager/watchdog
- Multi-gigabit serial interfaces from the FPGAs are brought out as I/O
- SpaceCube “core software” infrastructure includes cFS (Core Flight System) and “SpaceCube Linux” (with Xenomai)



SpaceCube

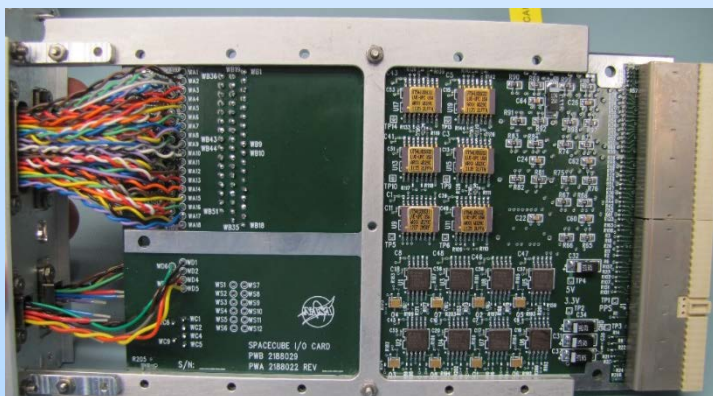
- Some existing hardware



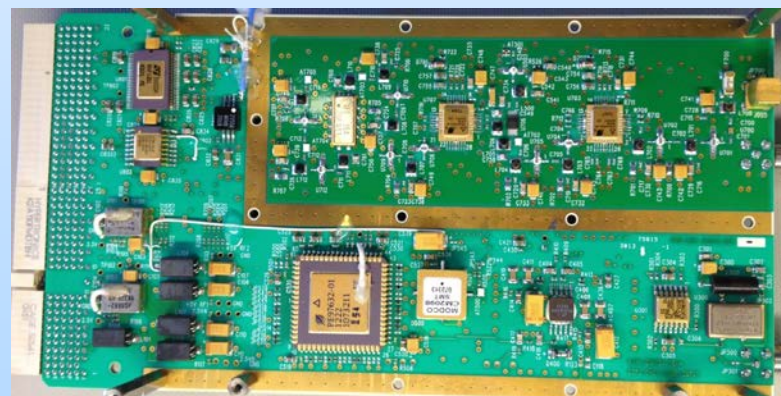
SpaceCube V2.0



SpaceCube V2.0 Processor Card



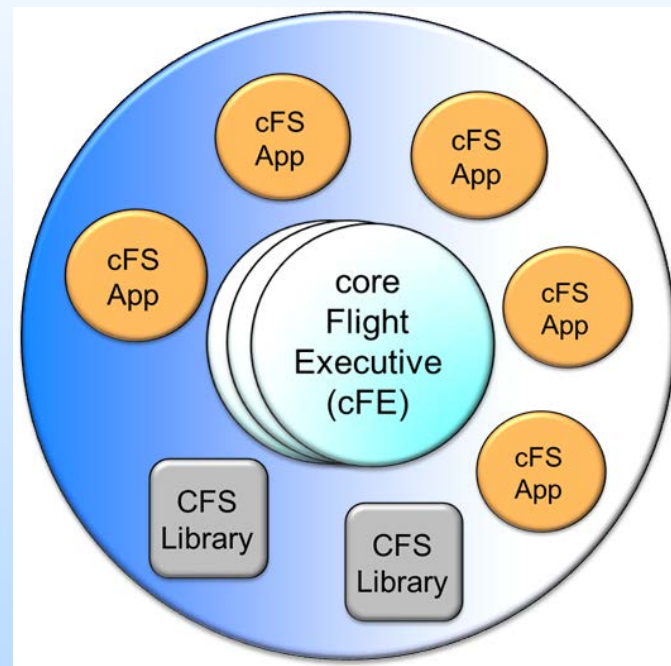
Restore-L Video/Spacecraft Interface Card



GPS RF Front-End Interface Card

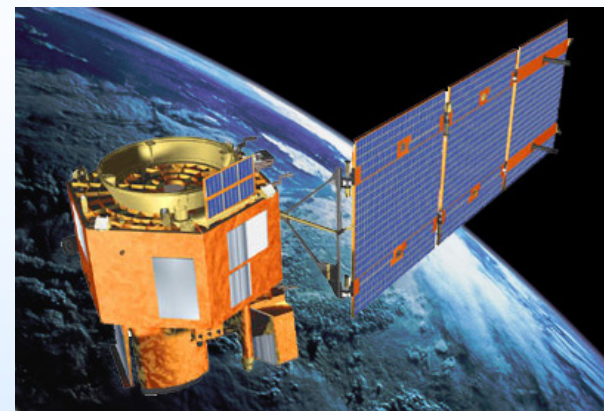
Core Flight System (cFS)

- **Across these architectures, GSFC uses Core Flight System (cFS) for flight software**
 - A Flight Software Architecture consisting of an OS Abstraction Layer (OSAL), Platform Support Package (PSP), cFE Core, cFS Libraries, and one or more cFS Applications
- **core Flight Executive (cFE)**
 - A framework of mission independent, reusable, core flight software services and operating environment
 - Layered on top of, and linked with the OSAL, PSP, and OS
- **cFS App**
 - Loosely coupled component using only OSAL, PSP and cFE defined interfaces
- **cFS Library**
 - Collection of common application services using only OSAL, PSP, and cFE defined interfaces

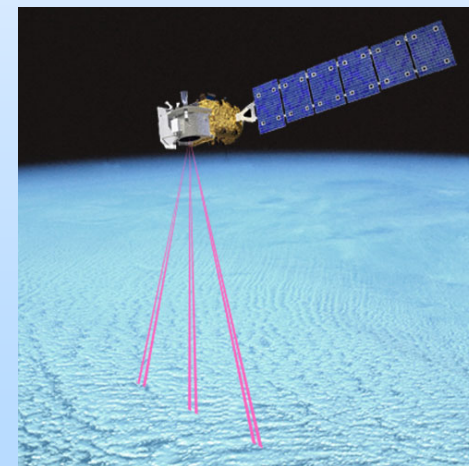


Future Requirements Drivers

- **Increased sensor data rates**
 - Synthetic Aperture Radar (SAR)
 - Hyperspectral Imagery
 - Lidar
 - Video
- **Increased downlink rates**
 - Ka-Band
 - Optical
 - Not keeping up with sensor data rates
- **Increased onboard science data processing**
 - Real-time event/feature detection
 - “Intelligent Instrument” data selection/compression
 - On-board data volume deduction
 - Real-time calibration/correction
 - On-board classification
 - On-board product generation



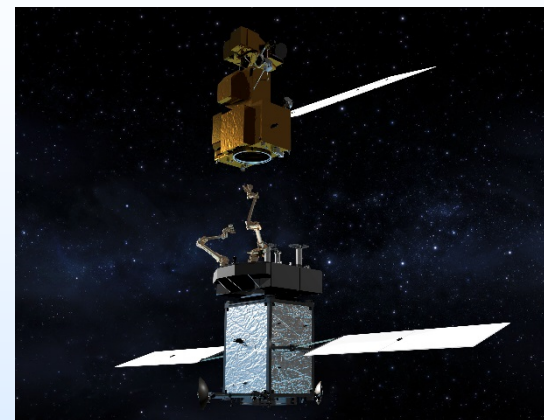
EO-1 Mission



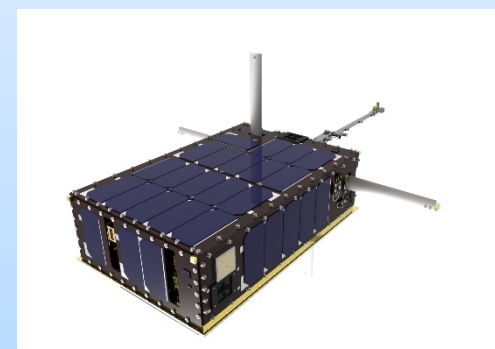
ICESAT-2 Mission

Future Requirements Drivers

- **Autonomous mission applications requiring high bandwidth processing**
 - Precision formation flying
 - Autonomous navigation
 - Autonomous rendezvous and docking
 - Terrain relative navigation
 - Real-time sensing and control
 - Real-time image processing
- **Improved resource efficiency for small mission classes**
 - Tightly integration of spacecraft and instrument functions
 - Share resources between spacecraft and instrument functions where possible
- **Distributed space missions with inter-platform collaboration**



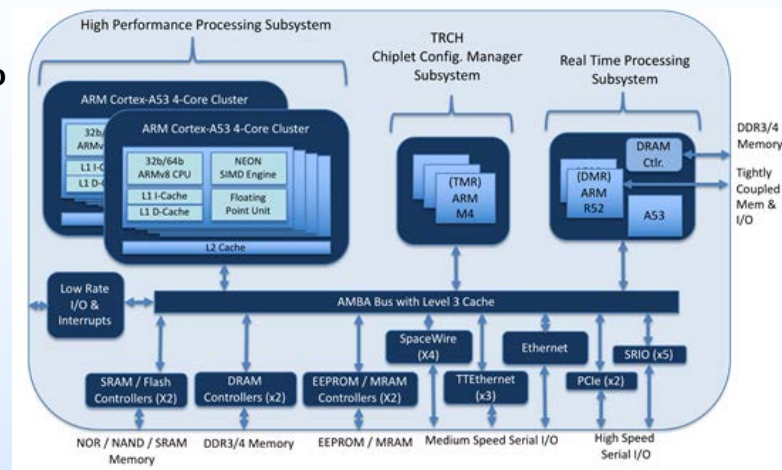
Restore-L Mission



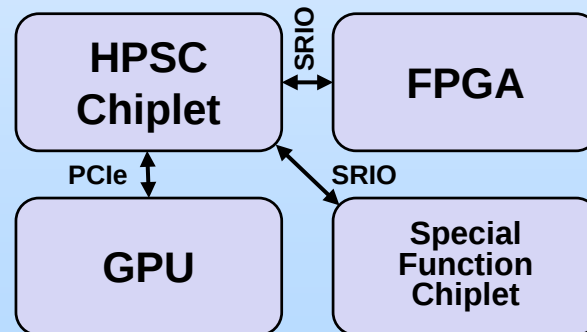
Dellinger Cubesat

How Future Architectures Can Meet These Needs

- **Use HPSC widely across mission classes**
 - Chiplet power, performance, and fault tolerance scalable to meet specific mission needs
 - Middleware significantly reduces the complexity of developing applications for the HPSC Chiplet
- **Employ “hybrid processing architectures”, leveraging different compute devices for what they’re best suited**
 - HPSC Chiplet
 - Graphics Processing Units (GPUs)
 - FPGAs
 - Special function “chiplets” implemented as ASICs
- **Increase network bandwidths**
 - Within boxes and between boxes
- **Promote IP architectures and standards**
 - Efficient development of System-On-a-Chip (SOC) devices
 - “Software defined spacecraft” for small mission classes
- **Use “managed COTS” (Commercial Off the Shelf) where appropriate**
 - Understand radiation susceptibilities
 - Determine appropriate mission applications
 - Employ “layered” fault tolerance
 - Consider resource implications of fault tolerance scheme



HPSC Chiplet



Hybrid Processing Architecture



Current Challenges

- **How best to leverage HPSC in our hardware architectures**
 - Optimal processing partition between processor elements within hybrid architectures
 - Signal integrity, EMI/EMC (Electromagnetic Interference / Electromagnetic Compatibility) and management of multiple (up to 24) high frequency (10GHz) interconnects
 - Providing multiple power services and ensuring power/ground quality
 - Adaptation of slice architecture to accommodate high speed networks
- **How best to leverage HPSC in our software architectures**
 - Adaptation of cFS to HPSC
 - Combination of mixed criticality applications in a complex multicore processing environment
 - Image/signal processing libraries ported to HPSC
- **Technology needs**
 - Intelligent, fault tolerant, multi-output Point-of-Load (POL) conversion
 - Advanced spaceflight memories
 - Next generation radiation tolerant FPGAs
 - “Special Function” chiplets with SRIO (Serial RapidIO) connectivity
 - Fault tolerant IP architectures, standards, and libraries



Current Challenges

- **Smallsat needs**
 - Smallsat subsystems and components with sufficient reliability and radiation tolerance for long duration missions in harsh environments
 - Standard onboard network interfaces
- **Use of COTS**
 - Growing reliance on COTS
 - Increasing complexity of COTS devices
 - Shortened product lifetimes
 - Reduced availability of radiation test facilities
 - Reliance on board-level or box-level radiation testing
- **Cybersecurity**
 - Increased attention within NASA
 - But no specific requirements have yet been levied on GSFC avionics
- **AI and deep learning in space**
 - Assessing potential onboard AI and deep learning applications
 - Defining the optimal flight architectures to implement them