Spaceborne Processor Array in Multi-Functional Structure (SPAMS)

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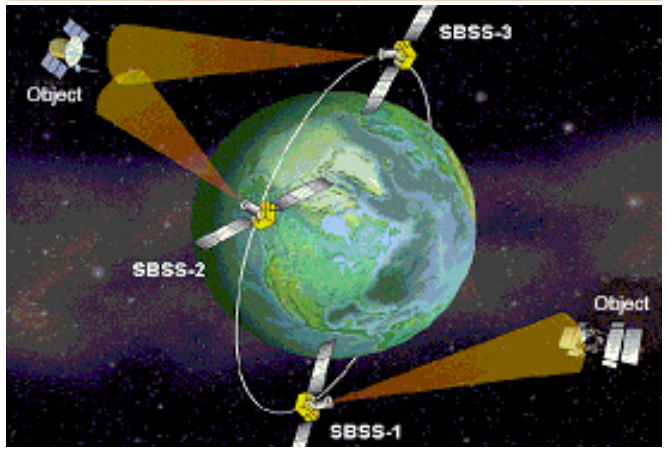
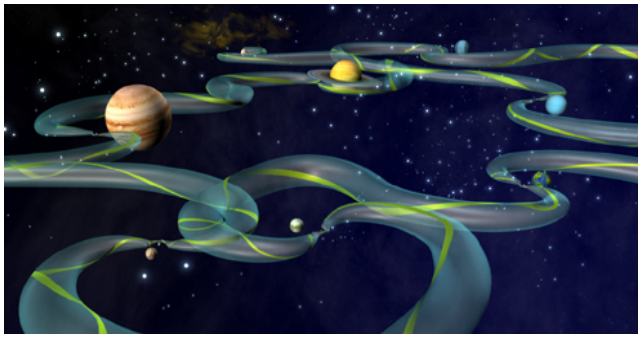
Introduction

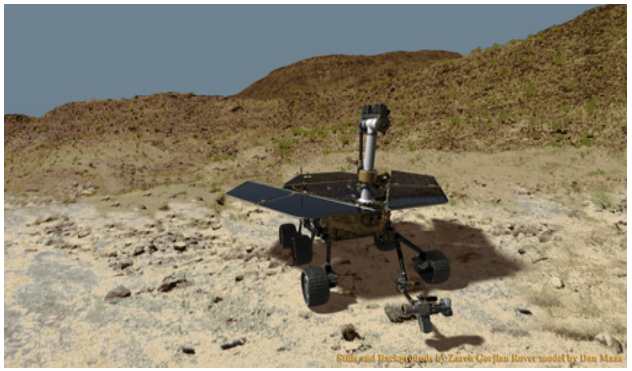
- **Future NASA missions require high performance on-board processing capability yet will be severely limited by mass.**
  - Autonomous Science
  - Constellation Control
  - Formation Flying
  - Virtual Presence
- **DoD space programs such as Space Superiority can also benefit from high performance on-board processing.**
  - Space Situational Awareness
  - Real-time Spacecraft Tracking
  - Autonomous Operations Under Interferences



Future Autonomous Mission Drivers

- **Interplanetary Navigation**
  - Low thrust in-orbit
  - Lagrange point
- **Entry Descent & Landing**
  - Flight control thru disparate flight regimes
  - Landing zone identification
  - Lateral winds
  - Soft touchdown
- **Surface Mobility**
  - Terrain traversal
  - Obstacle avoidance
  - Science Target identification
  - Exploration sequencing



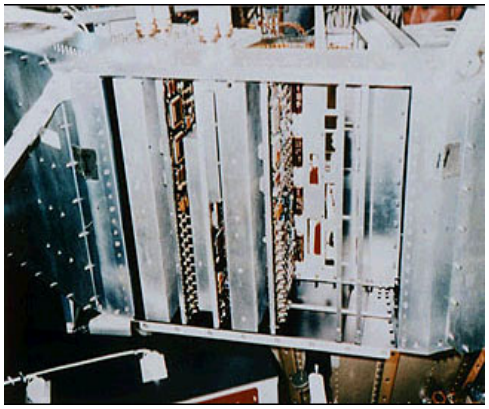


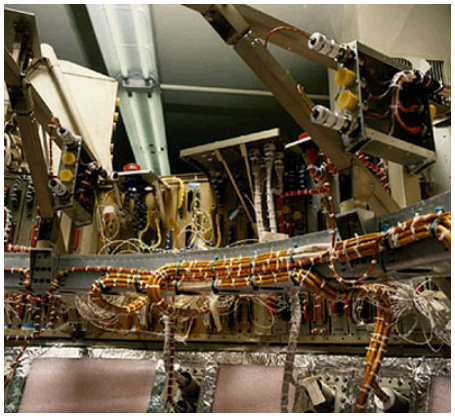
Future Mission Requirements

- **Teraflops' in space**
  - Satisfy wide range of mission drivers
- **Ultra low energy per operation**
  - Towards > 100 Gops/watt
- **Numeric and Symbolic high performance computing**
  - Numeric for remote sensor data analysis and knowledge extraction
  - Symbolic for real-time context-aware planning and goal-directed contingency response
- **Long duration fix-less operation**
  - Multi-decade
- **Size and weight**
  - Small enough to fit in constrained volume
  - Light enough to be applied to virtually all autonomous mission profiles and costs
- **Scalable**
  - Up to high performance in space
  - Down to smallest possible mission packages
  - Single software stack hierarchy and cognition model
    - High reliability software
    - Low software development time

Current Spacecraft Electronics

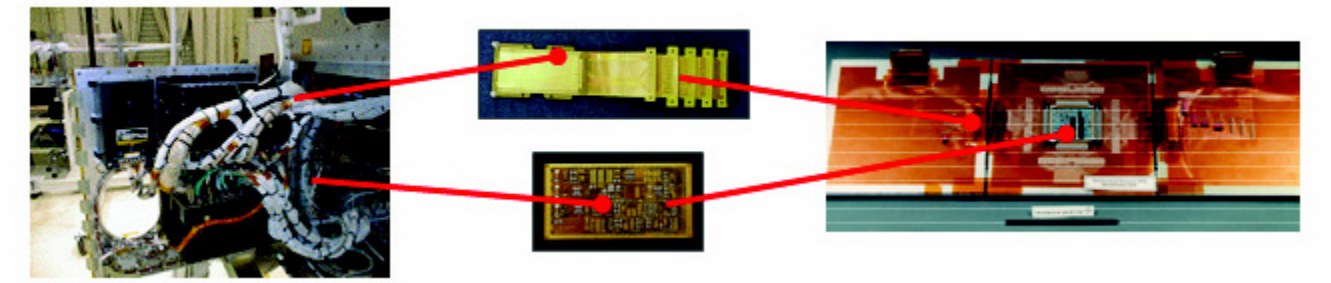
- Centrally Located Chassis and Backplanes.
- Aluminum or Titanium Based Structural Members.
- Heavy and Complicated Wiring Cables.
- High Performance Computers Often Sacrificed During Spacecraft Trade-off Analysis.





Multi-Functional Structure (MFS) Technologies

- **The NASA, AFRL, MDA, SMC, and DARPA have also been supporting the technology development of the MFS .**
  - NASA Deep Space–1, NASA EOS-1, Boeing Delta IV ELV, and Global Hawk UAV.
- **Spacecraft built with MFS can have:**
  - >50% mass reduction.
  - >2x volume saving.
  - Support mass production of spacecraft for constellations
- **Most MFS work focuses on embedding lightweight, flexible circuits into composite structures.**



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*** AFRL**

SPAMS Objectives

- **On-demand supercomputer level performance aboard spacecraft.**
- **High performance processing without increase to spacecraft mass.**
- **Dynamic ultra low power consumption.**
- **Long lifetime fault tolerance.**
- **High survivability in hostile environments.**

PC Board Material Property

Material	Thermal Conductivity (W/m*K)	CTE (ppm/C)	Density (g/cm^3)	Tensile Modulus (msi)
ST325 [1]	325	-1.15	2.17	114.0
FR4 [1]	8.0	17.00	1.80	2.4
Polyimide [1,2]	0.3	16.50 X,Y dir	1.70	3.0
Copper [1]	385	17.00	8.92	12.0
Al 100%[1]	240	24.00	2.70	10.2

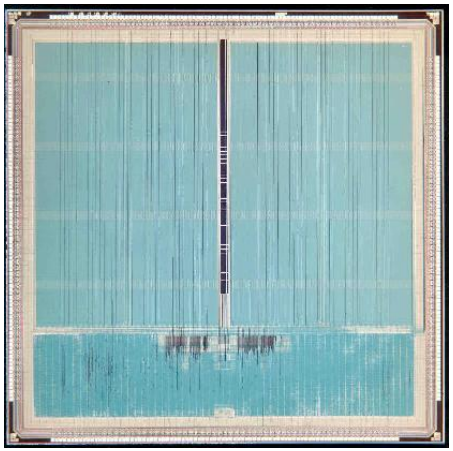
References
[1] Technology Overview, from Thermal Works website: http://www.thermalworks.com/marketing/STABLCOR%20Properties%20Chart.pdf accessed 4/20/06
[2] Internal JPL verbal communication- Results of TMA testing

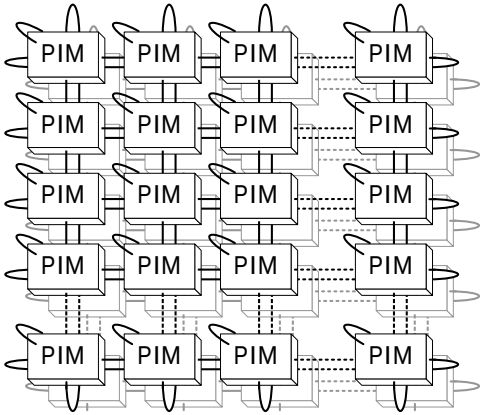
SPAMS Approach

- **Instead of embedding flexible circuits into composite structures, SPAMS takes advantage of the strength characteristics from the new composite materials and builds the spacecraft structure members with printed circuit boards.**
  - Direct Die Mounting on PC Boards.
  - Unlimited Expandability for Array Processors.
  - High Survivability.
- **Integrate with Gilgamesh M*emory,* I*ntelligence, and* N*etwork* D*evice* (MIND) multi-core in-memory computer architecture into a single, system super-architecture.**
  - Ultra High Performance
  - Ultra Low Power
  - Long Duration Fault Tolerance.

MIND Strategy

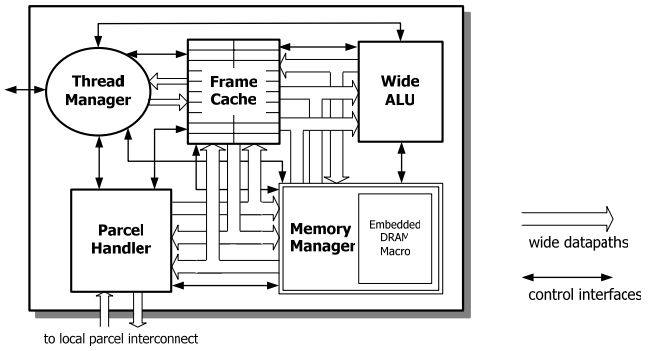
- **Multi-Core Memory**
  - Very low power
  - High memory bandwidth
  - Low memory access latency
  - Single system image for scalable computation
- **Graceful Degradation**
  - Exploits repetitive structures and redundant data paths
  - High reliability with no maintenance
  - Reconfiguration for fault isolation
- **Active Power management**
  - Decrease average power consumption
- **Real time processing**
  - Control of actuators and post sensor processing
- **Advanced execution model for efficient scalability**
  - Message driven-computing split-transaction
  - Multithreaded task control
  - Lightweight synchronization
  - Dynamic parallelism





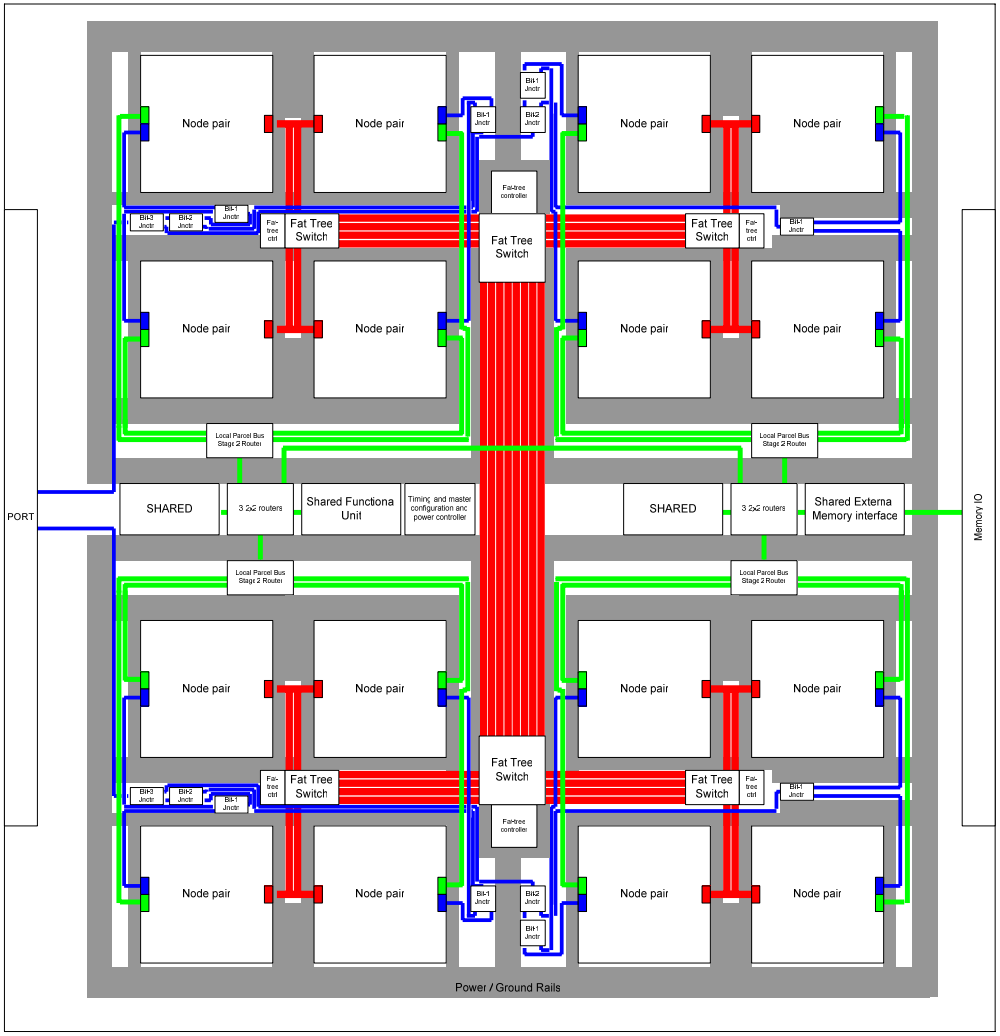
MIND Architecture

- **Parcel active message driven computing**
  - Decoupled split-transaction execution
  - System wide latency hiding
  - Move work to data instead of data to work
- **Multithreaded control**
  - Unified dynamic mechanism for resource management
  - Latency hiding
  - Real time response

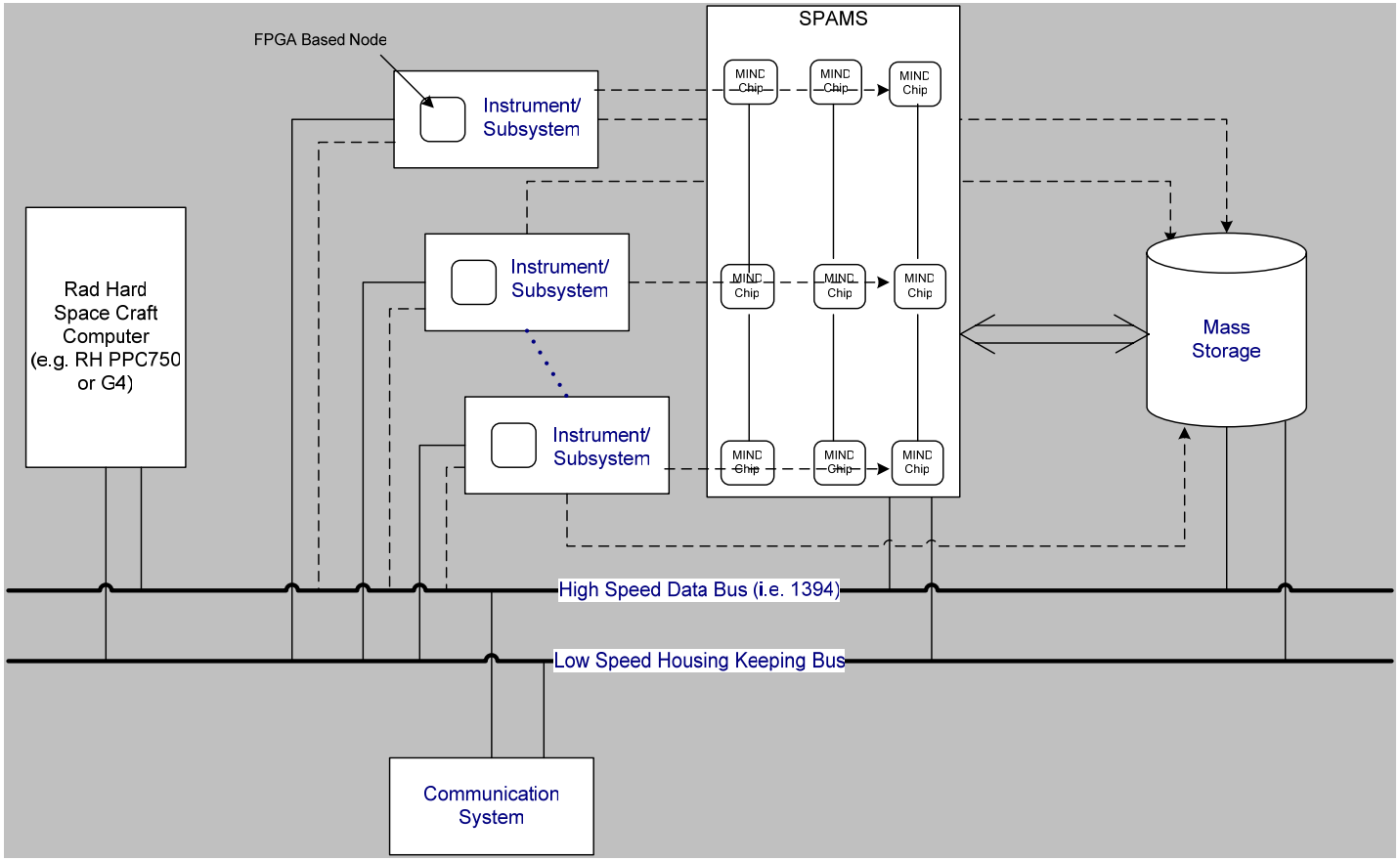


- **Virtual to physical address translation in memory**
  - Global distributed shared memory thru distributed directory table
  - Dynamic page migration
  - Wide registers serve as context sensitive TLB
- **Graceful degradation for Fault tolerance**
  - Graceful degradation through highly replicated fine-grain elements.
  - Hardware architecture includes fault detection mechanisms.
  - Software tags for bit-checking at hardware speeds; includes memory scrubbing.
  - Virtual data and tasks permits rapid reconfiguration without software regeneration.

MIND Multi-Core Chip Layout

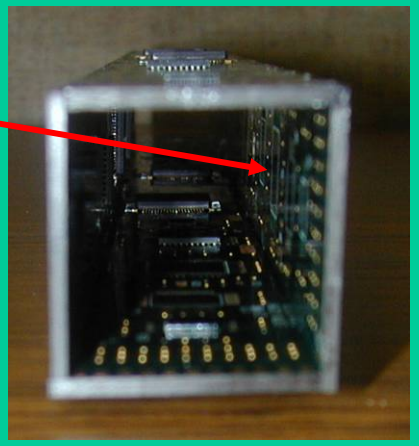


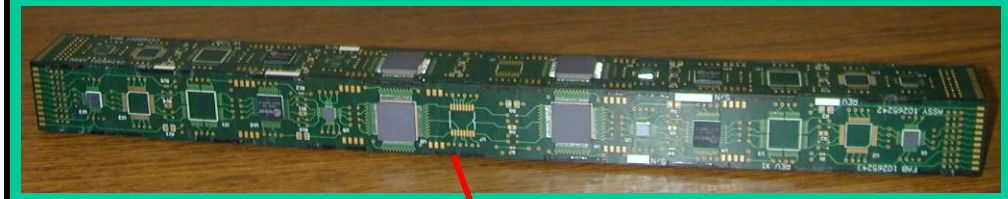
SPAMS Architecture



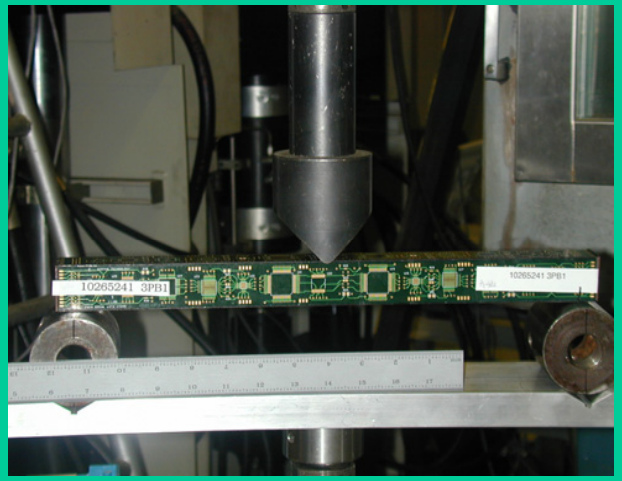
SPAMS Implementations

Wiring cables are built inside the structure elements.



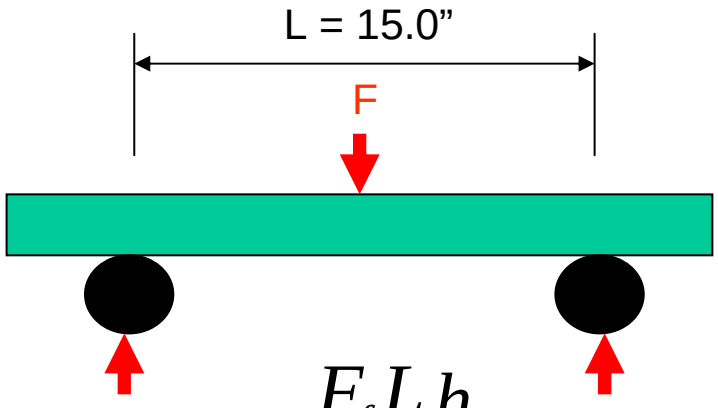


Spacecraft instrument chassis and structure members are made of fault tolerant high performance computer boards.



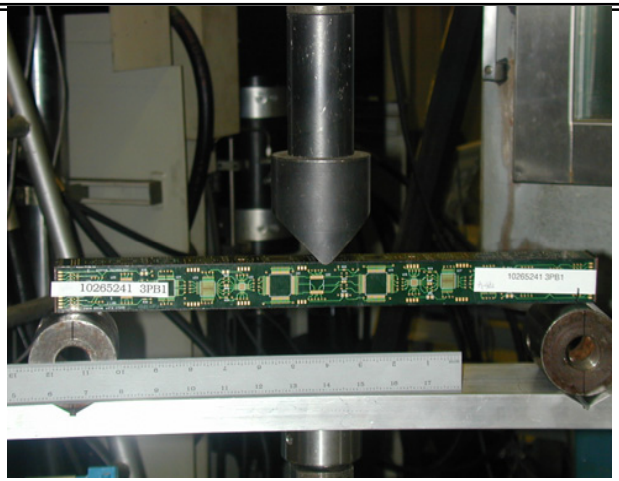
3-Point Bend Test

3-Point Bend Test: Polyimide Box Beam

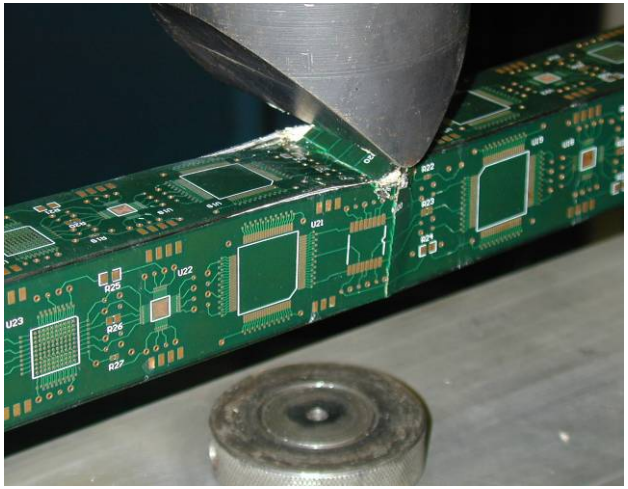


$$\sigma = \frac{F_f L}{CI} \frac{h_o}{2}$$

Where:
F_f= Fracture Force
L = length
h_o=thickness of beam
I = moment of inertia
C = constant
C = 4 (3-pt bend)

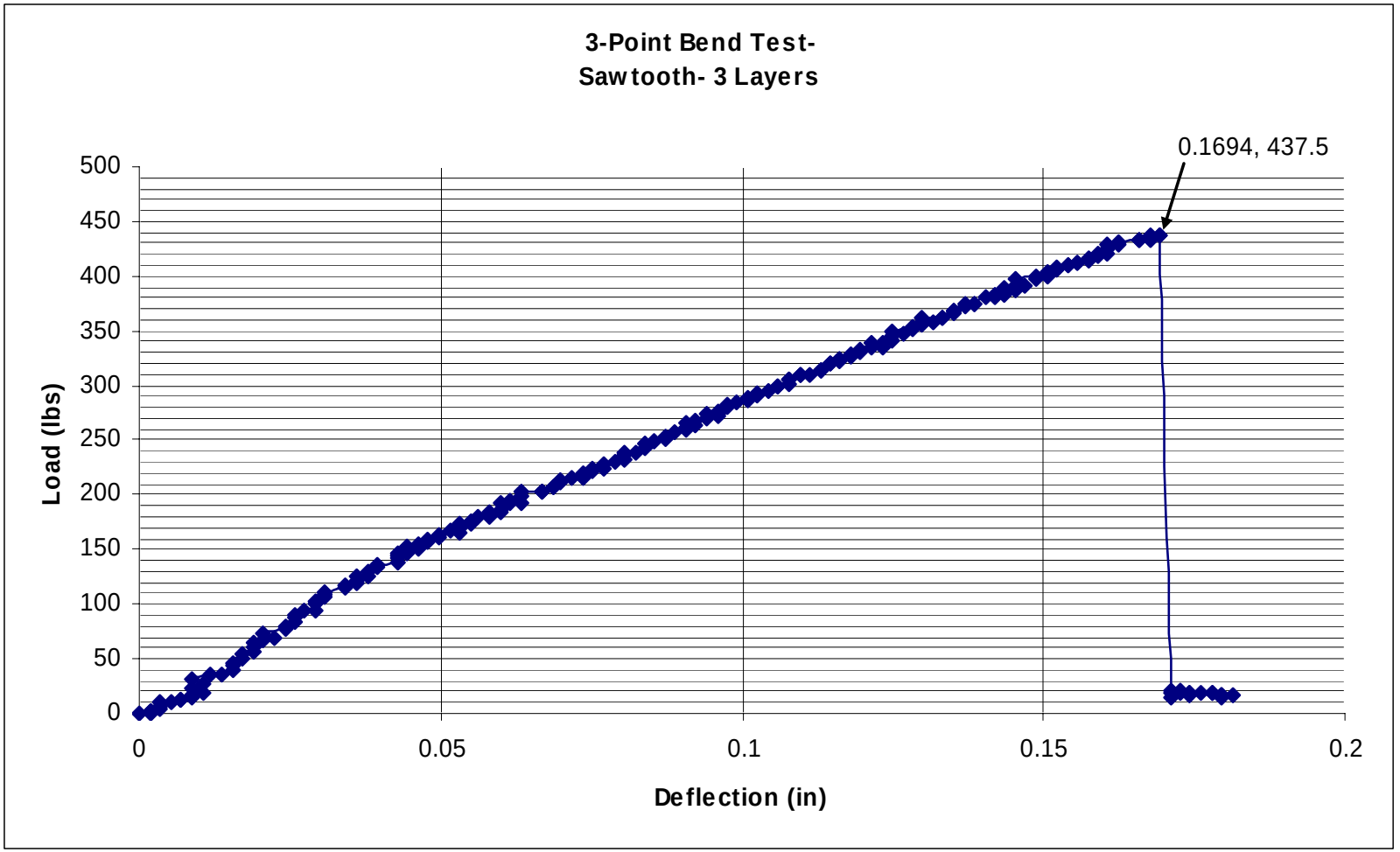


Test Set-up: Start

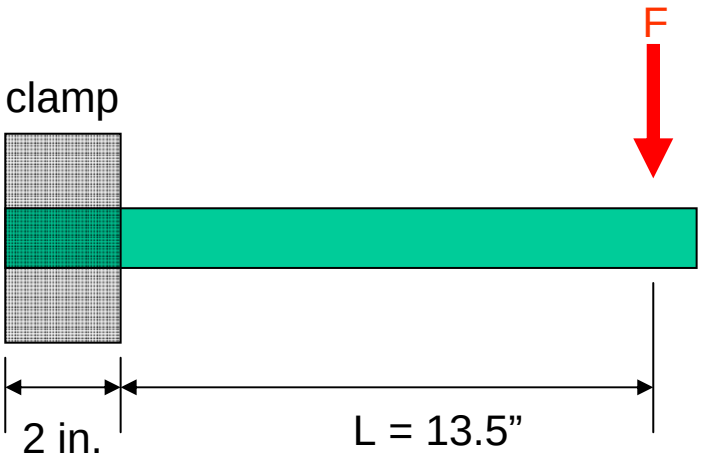


Test Set-up: Fracture

3-Point Bend Test: Polyimide Box Beam

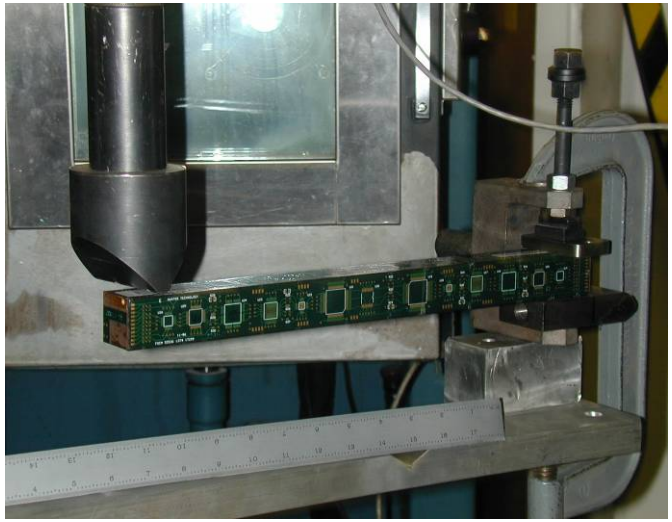


Cantilever Test: Polyimide Box Beam

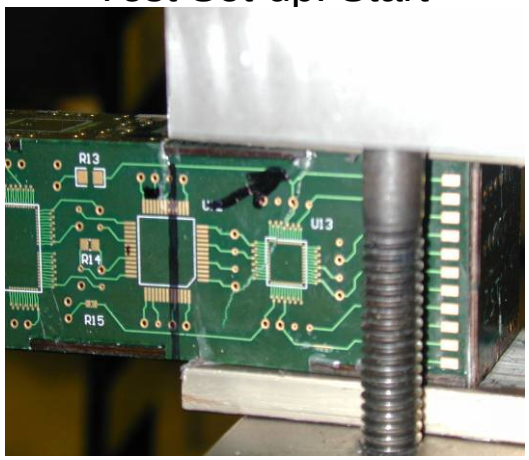


$$\sigma = \frac{F_f L}{CI} \frac{h_o}{2}$$

Where:
F_f= Fracture Force
L = length
h_o=thickness of beam
I = moment of inertia
C = constant
C = 1 for cantilever

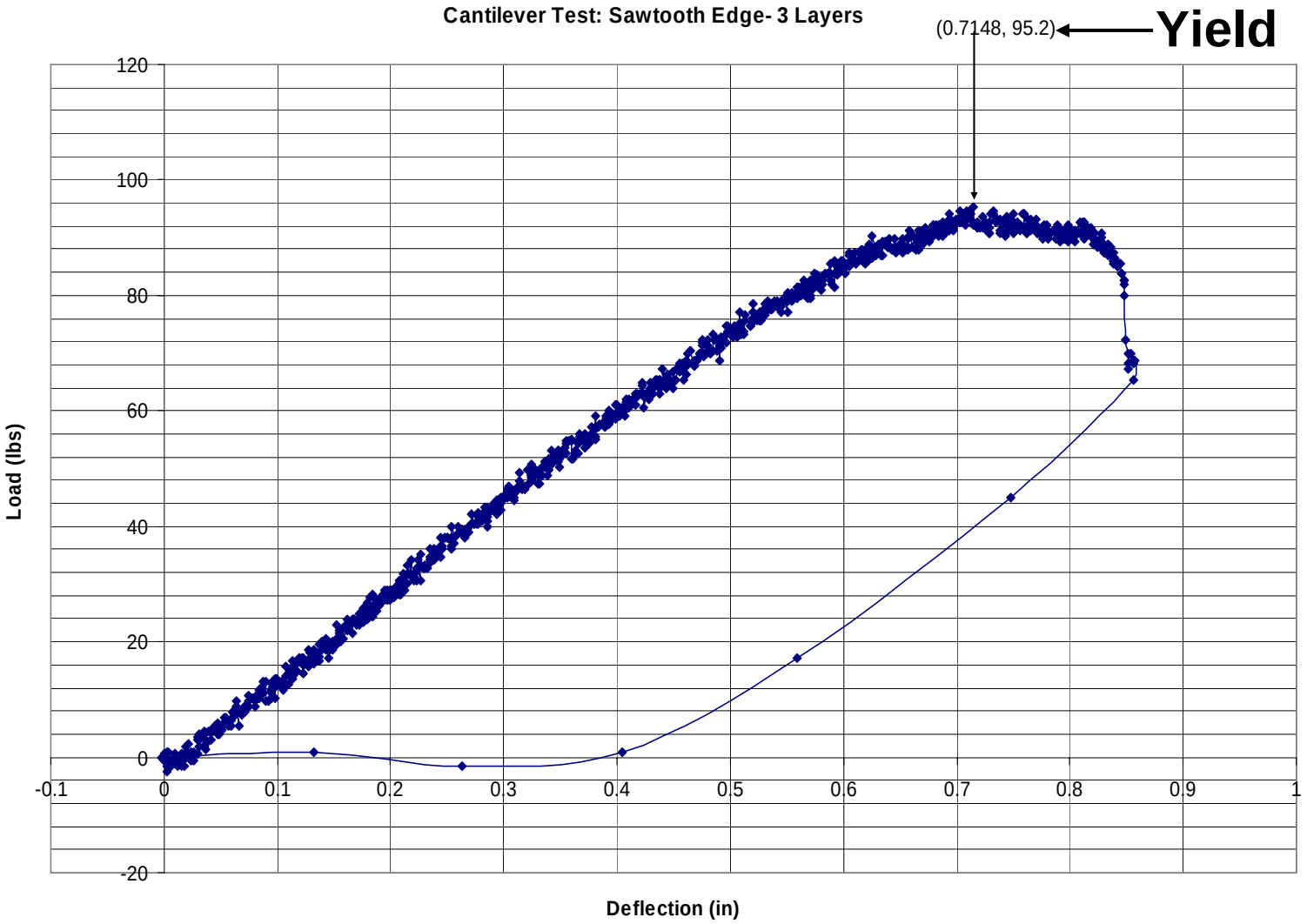


Test Set-up: Start



Test Set-up: Break

Cantilever Test: Polyimide Box Beam



Conclusion

- SPAMS can potentially provide high performance computing to spacecraft without sacrificing additional mass.
- Gilgamesh architecture allows SPAMS to provide high performance, low power, and long duration fault tolerance.
- We are building and testing different elements of the SPAMS.