Packaging, Plug-and-play, Modularity and the Impact of Wires

Dallas
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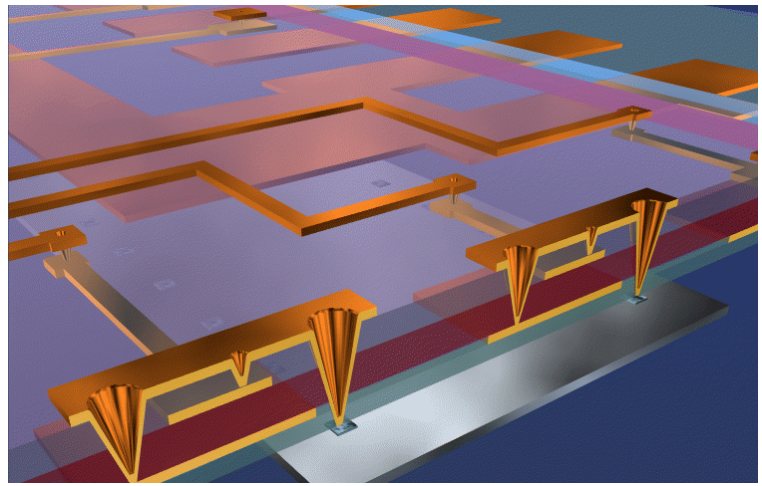
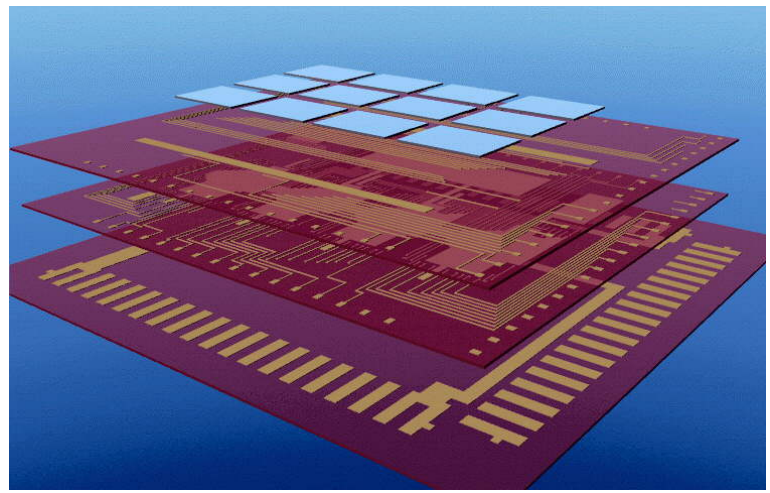
Outline

- Packaging and the “War on Wires”
- Nature of Wires
- The Pursuit of the Six-Day Spacecraft
- Some Eclectic Observations about Wiring

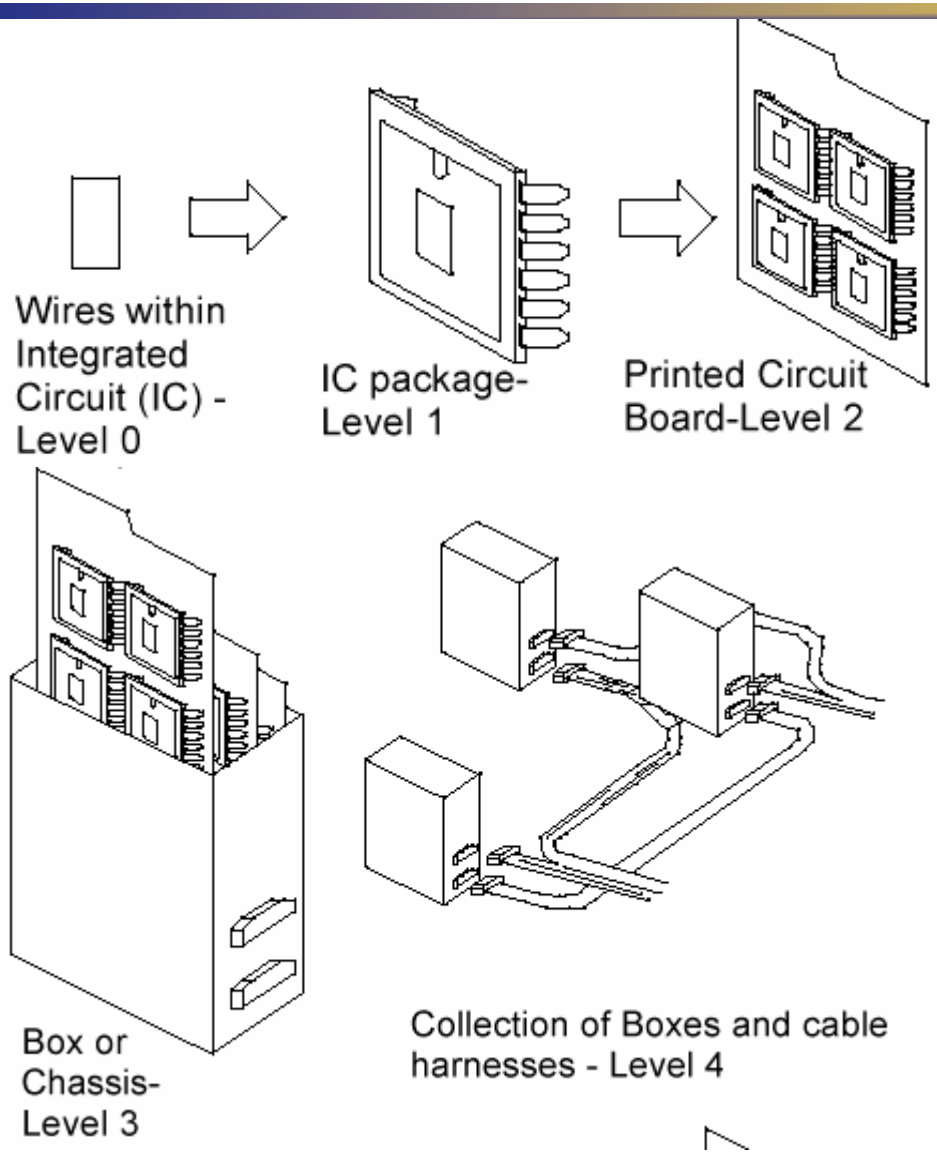
What is Packaging and Interconnect?

- Conductor/dielectric structures that provide:
  - Interconnection between terminals of devices within a system
  - power delivery
  - thermal management
  - protective enclosure
- Advanced vs. conventional packaging



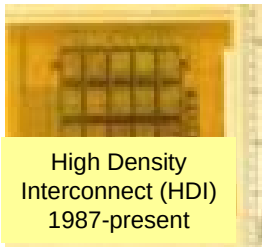


The Packaging Hierarchy



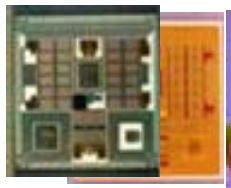
- **Packaging is like a structural bureaucracy**
- **Established and entrenched infrastructures that have evolved through "happenstance"**
- **Promotes view of packaging as a headache, necessary evil**

Twenty Years in Space Electronics Miniaturization

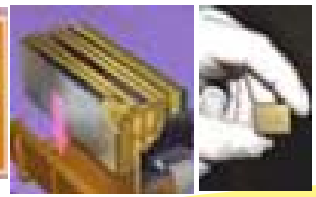


High Density Interconnect (HDI) 1987-present

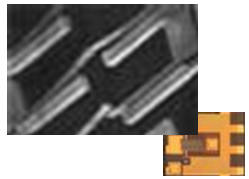
1990 – SPIRIT III/MSX



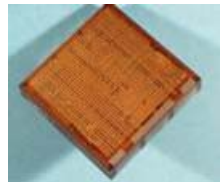
1991– Brilliant Pebbles



1992 – 2003 3-D packaging



1995 – 2005 Bistable MEMS

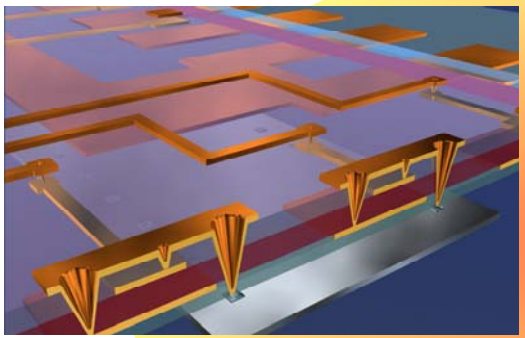


1998 – 2003 Miniature reconfigurable processors

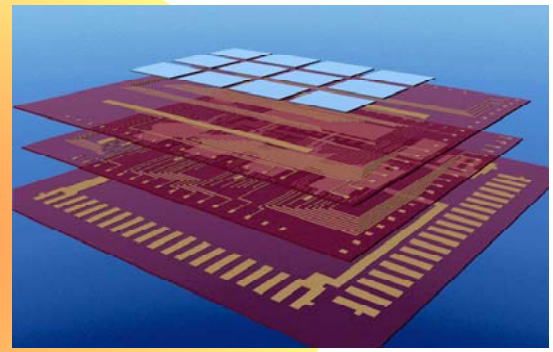
1998 – Microwave HDI

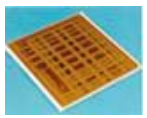
1999 – Plastic HDI

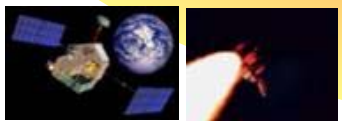
2004 – Ultra-dense 3-D



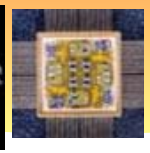
- Commitment to excellence with game-changing technologies
- A rich legacy of innovation and transition



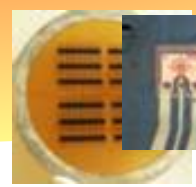


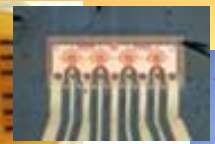


(HCSM) TRMM,HST Servicing Mission 2, MS1



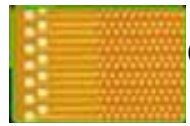
(PASM) GE-Americom





(VCSEL Module) F-16, JSF

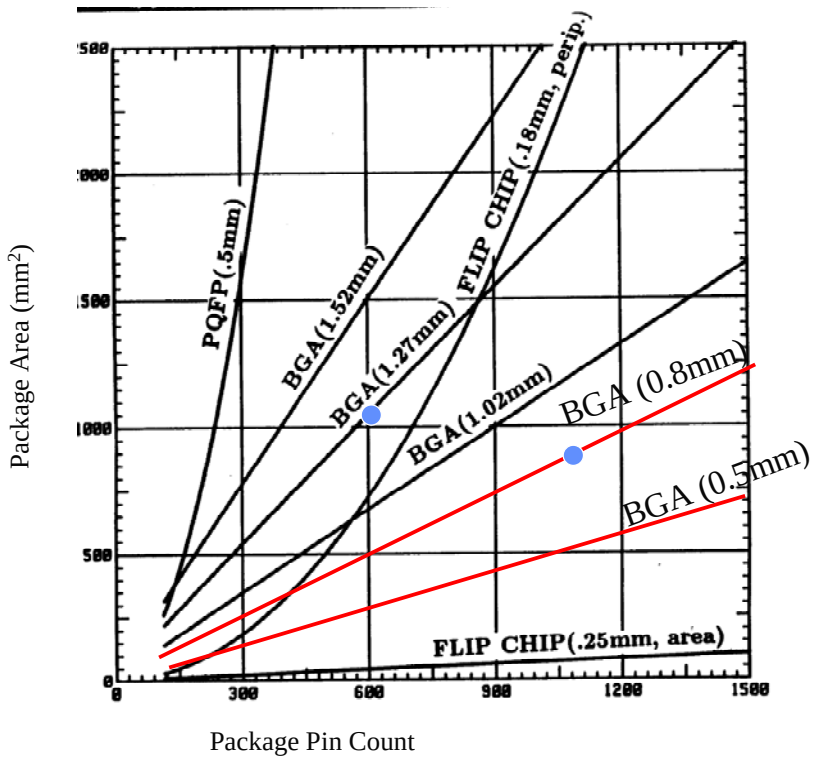
(AIC) DS2,JAWSAT,STRV-1D



(Flex) GEMS Ultrasound

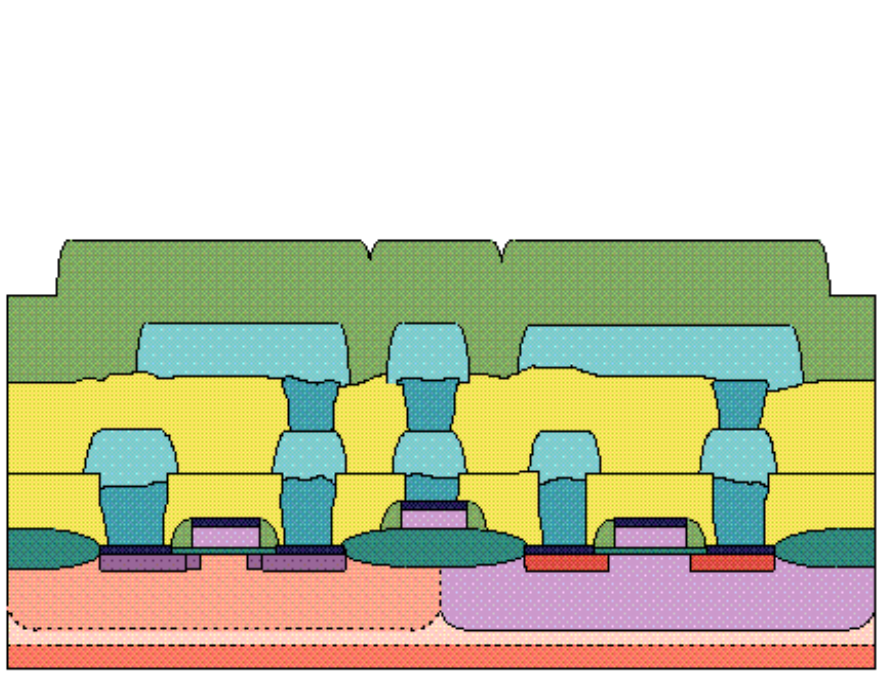
Evolution of Packaging Technology

- 2-D
  - multichip modules (MCMs)
  - Dense printed wiring boards
  - BGA, chip-scale packages
- 3-D
  - Stacked die
  - Stacked packages
  - Stackable MCMs



The challenge of interconnect

- **Comparison of integrated circuits in 1986 and 2004**



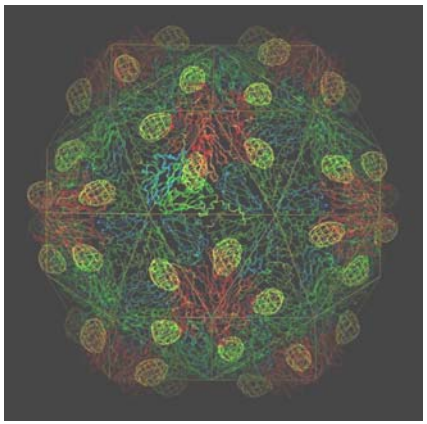
1.0 micron

0.1 micron

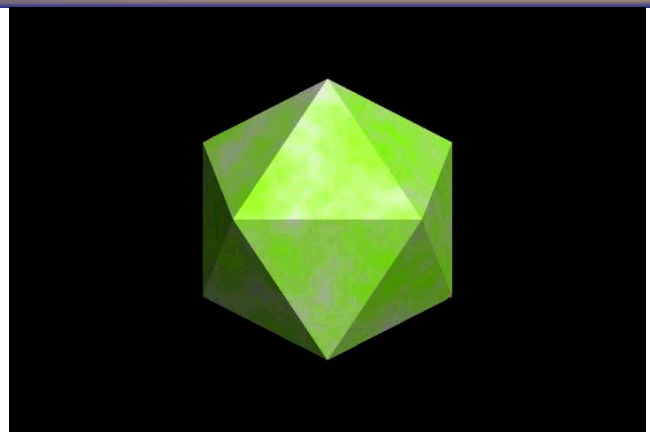
Drawn to the same scale

Chart courtesy of Ted Denlin, Sandia National Laboratory

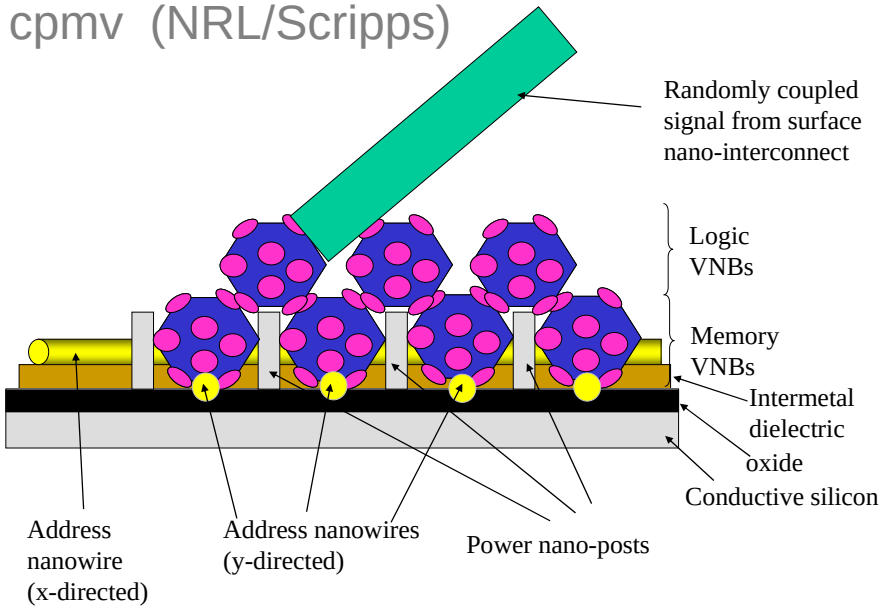
“Molecules-to-pins” Architecture Reconfigurable Cellular Arrays



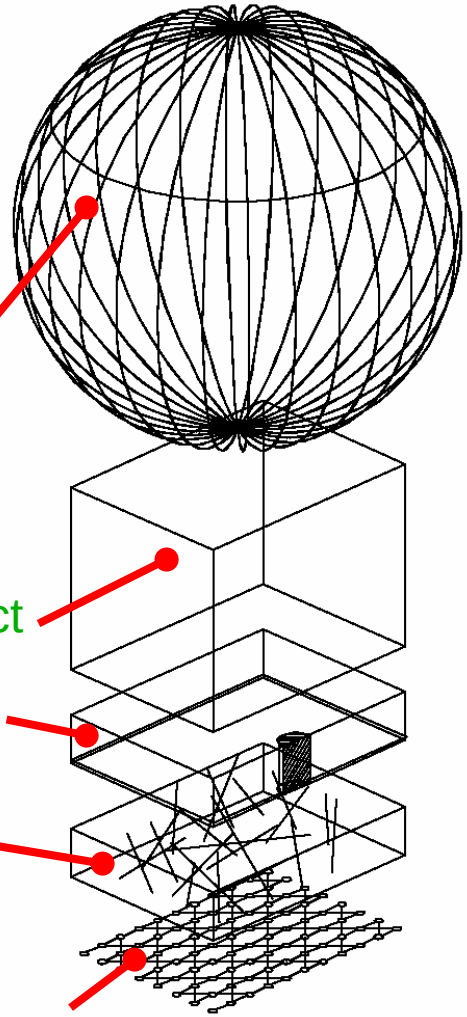
Cowpea Mosaic Virus
cpmv (NRL/Scripps)



AFRL animation



Cross-section of virus-based RCA tile

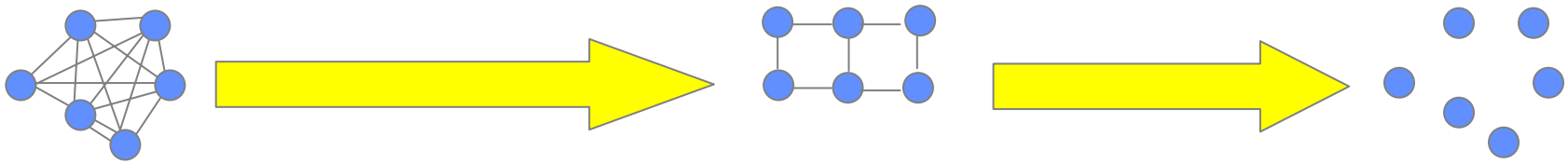


A War on Wires

- **What can be done?**

Nature of Wires

Wiring Demand Interconnectivity Ranges



fully connected
p~1

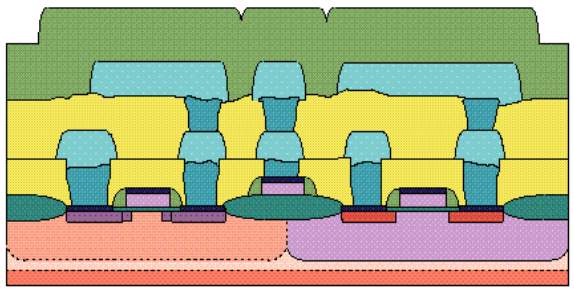
cellular automata
p~0.5

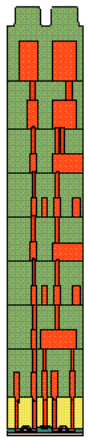
unconnected
p~0

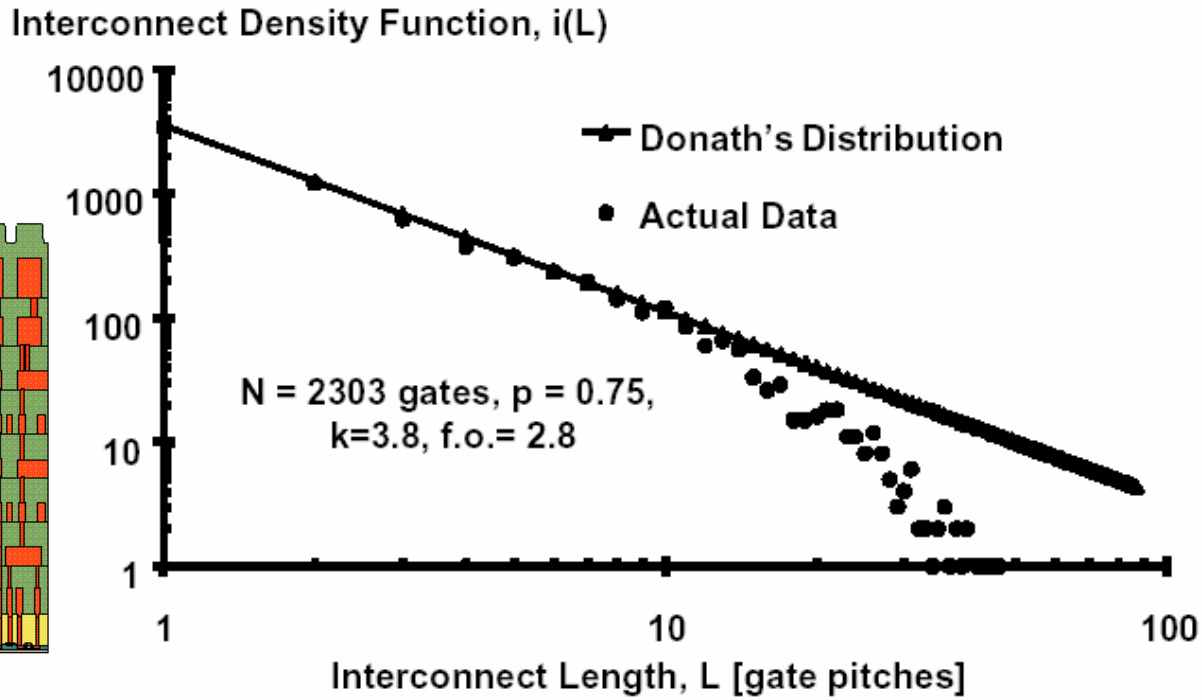
Wiring Models

- **Random Networks (Erdös-Renya)**
- **Small-World (Watts-Strogatz)**
- **Scale-Free (Laszlo-Barabasi)**

Scale-Free Networks in VLSI

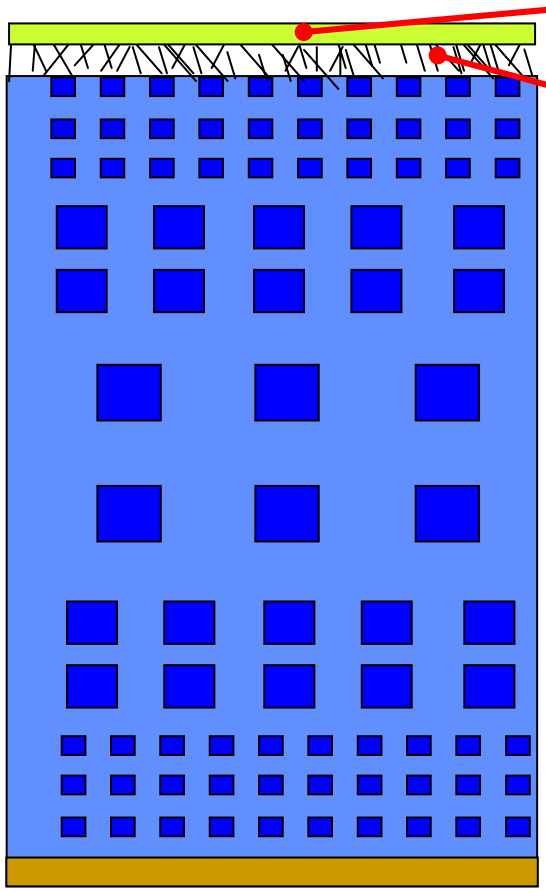


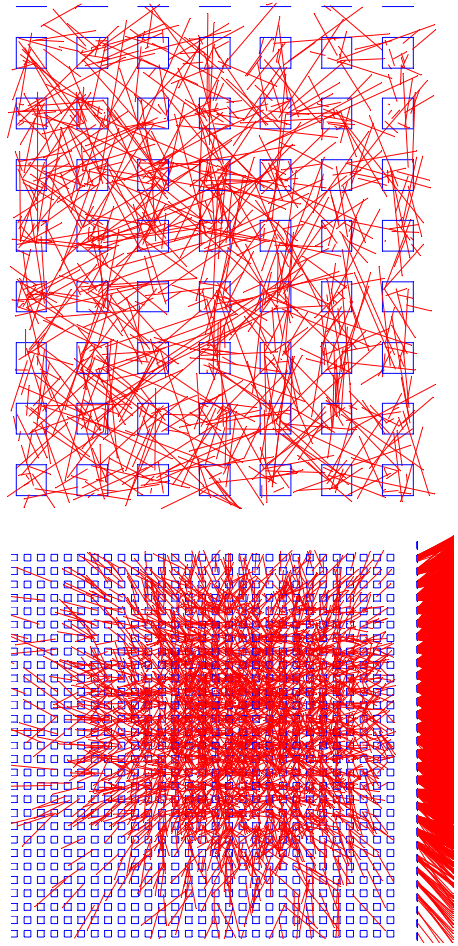




VLSI, Davis Phd thesis

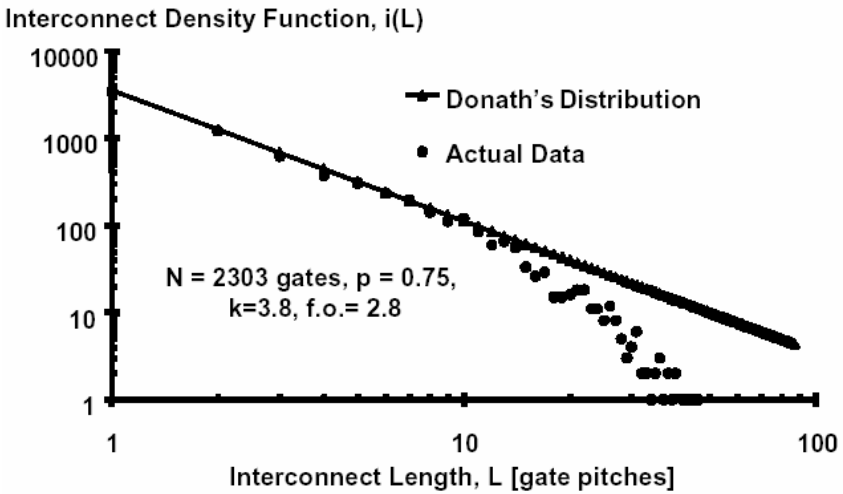
Nano-Interconnection Redistribution



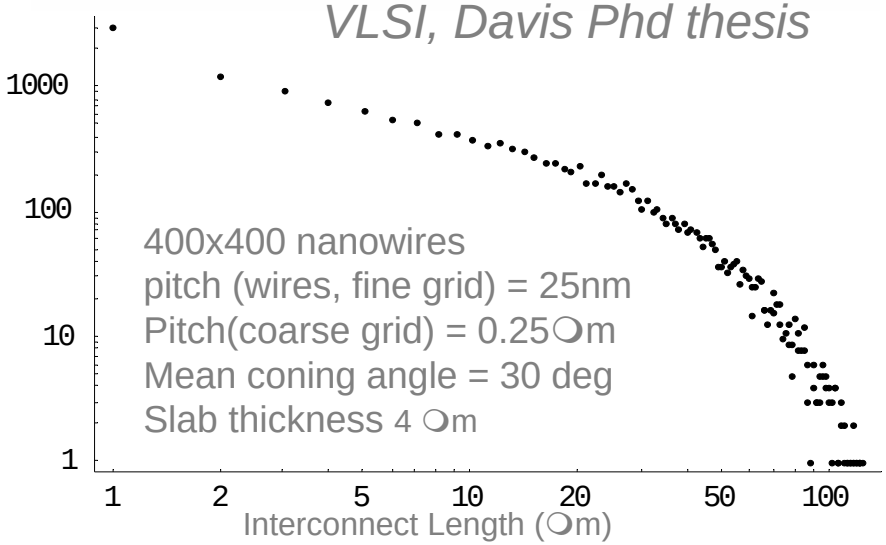


Simulated Distribution
Based on 3-D nanowire sticks

Distribution Results Based on Simulation



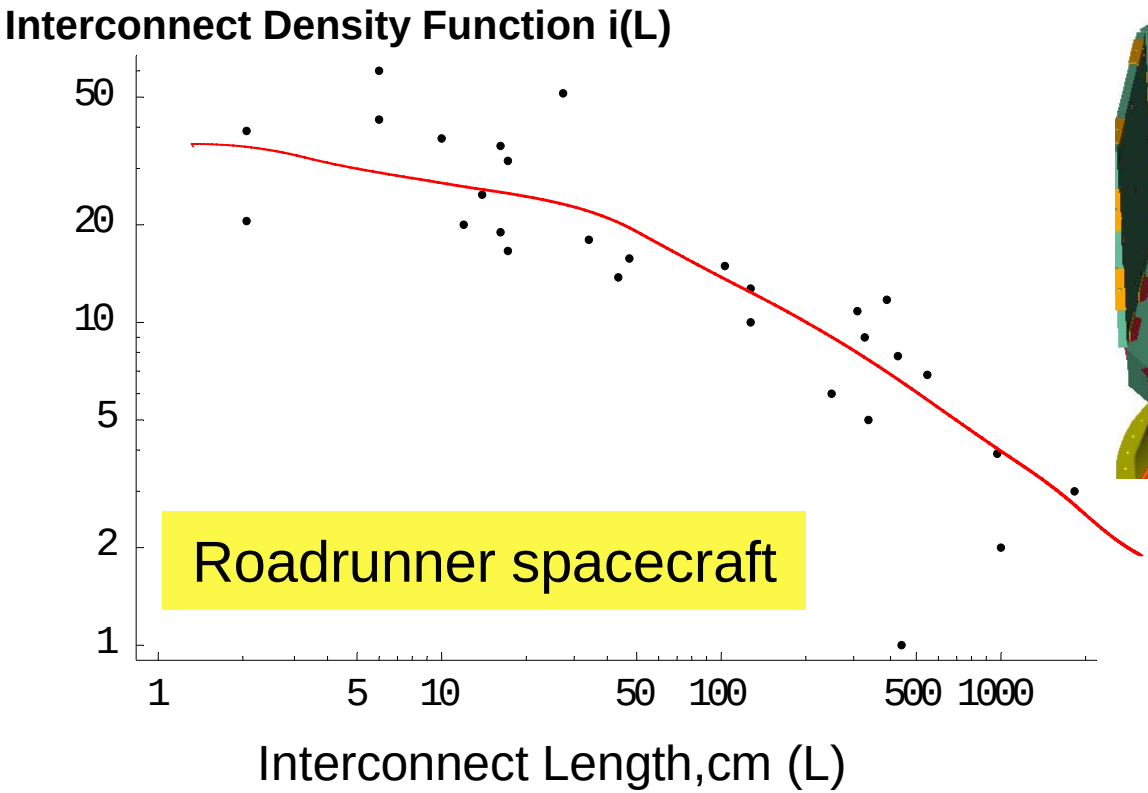
VLSI, Davis Phd thesis

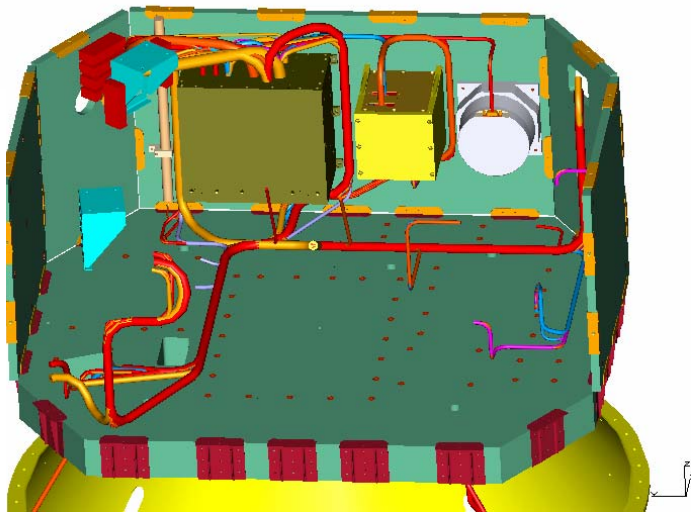


Simulation Results

- **3-D randomized distributions can mimic statistical behavior of complex VLSI systems**
- **Consistent with scale-free network model (*Barabasi 2002*)**

Distribution of Interconnections Science / Engineering of Wiring Systems





Owczarczak & Lyke (unpublished, 2005)

Interim Summary

- **Wiring demand in most systems we care about seems to follow a scale-free distribution**
- **Can't fight nature?**
- **If you can't beat them…**
  - **What can we do to exploit an understanding of the nature of wiring in systems**
  - **Can we structure wiring supply to follow demand?**

The pursuit of complex systems

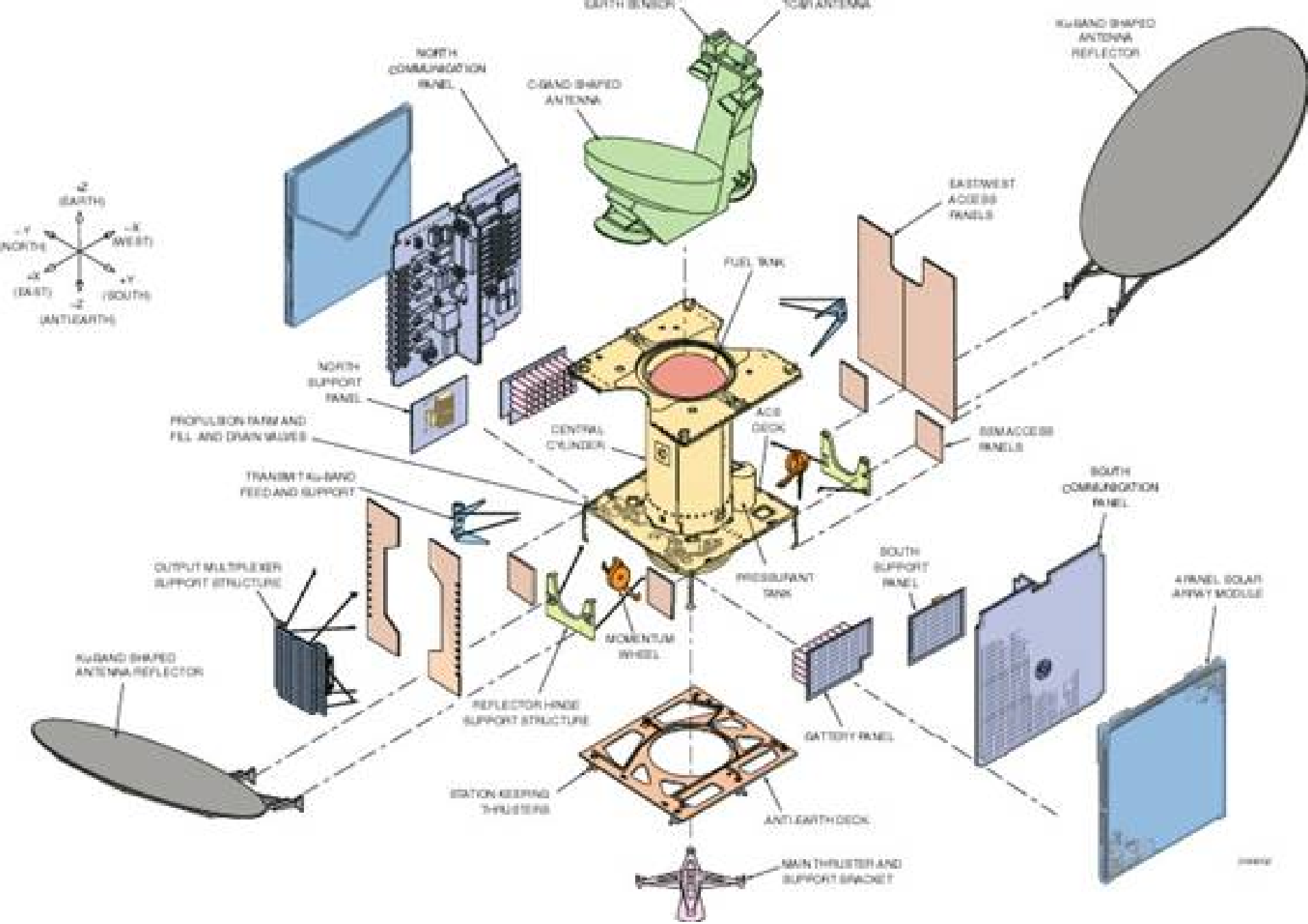
- **The needs of operationally responsive space**

Problem Formulation

- Create a spacecraft in less than one week

Days Instead of Years….

- **Cannot be achieved by “tweaking” existing processes**
- **Requires fundamentally new approaches**
- **Standards are not enough**



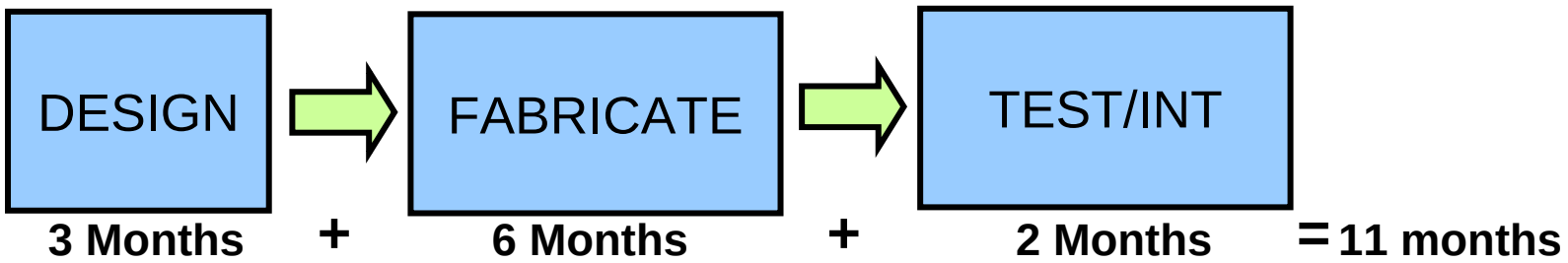
 Source: http://www.ssloral.com/html/products/satint.html

Sources of complexity: TIME DELAYS

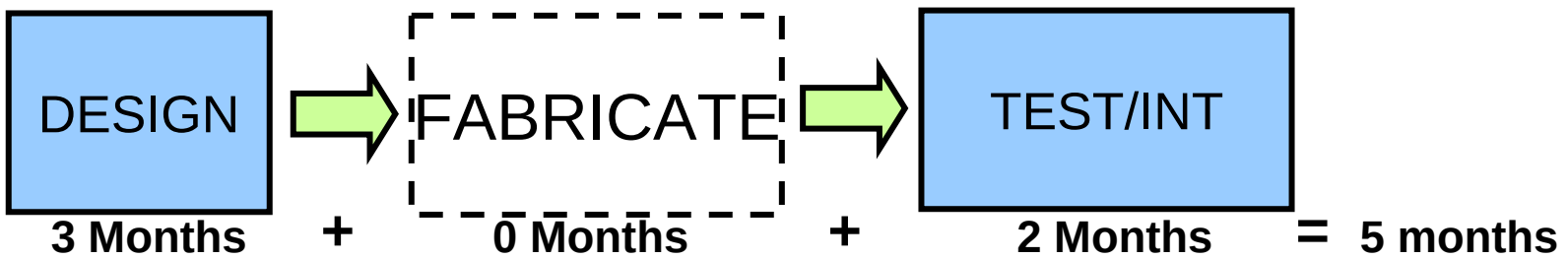
- **Long lead: Component development**
- **Uncertainty: Human errors in interpretation**
- **Long lead: Harnesses**
- **Long lead: Software**
- **Lack of effective modular strategies**
- **Requirements for precision in assembly, etc. counter to rapid integration**

Beating time delay – an example

Integrated Circuit (IC)



Field Programmable Gate Array (FPGA)



Convert one type of time delay into another kind you can deal with!

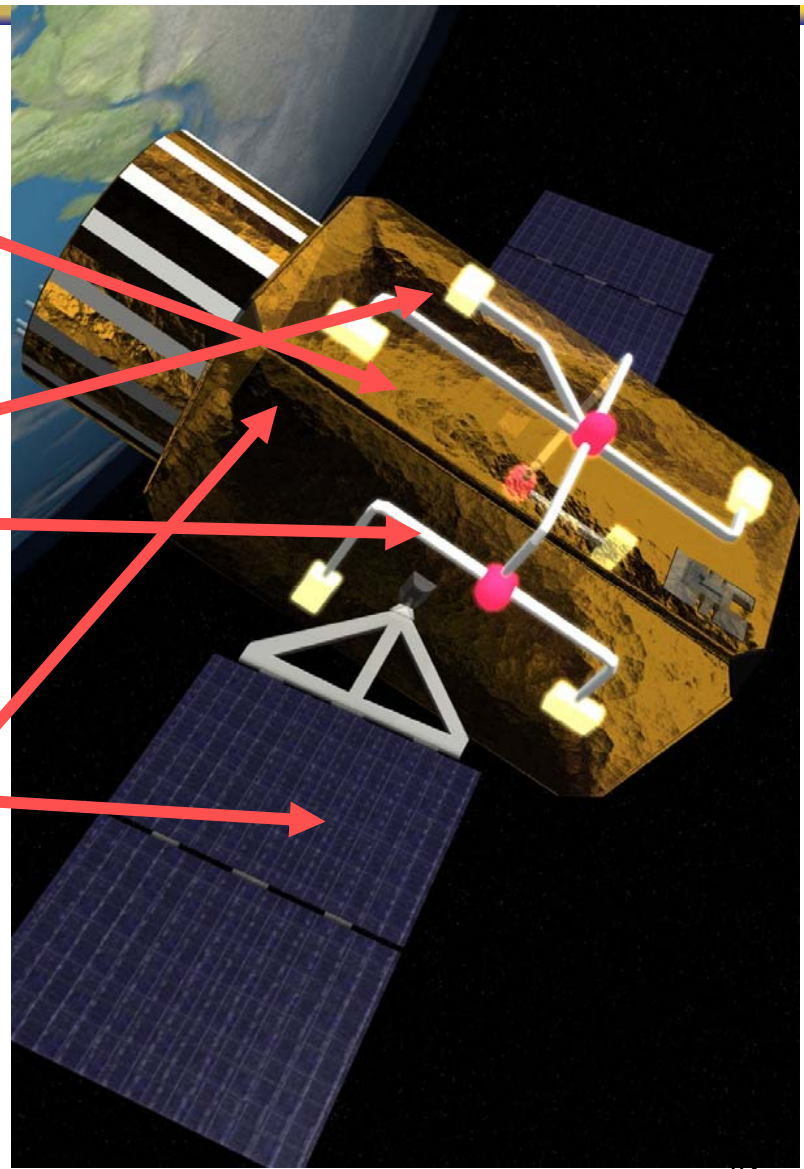
Opportunities for a “Field-programmable Satellite”

Eliminate wiring harnesses with pre-built programmable wiring

Integrate plug-and-play components into sockets of pre-built panels

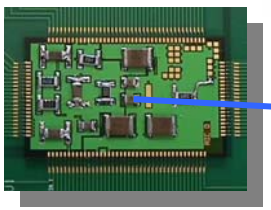
Modularize power system components, add “smart combiners”

Programmable communications with software radio technology

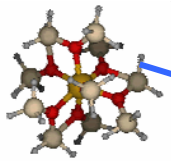


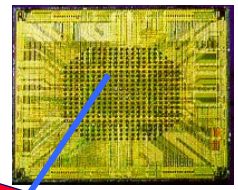
Reconfigurability

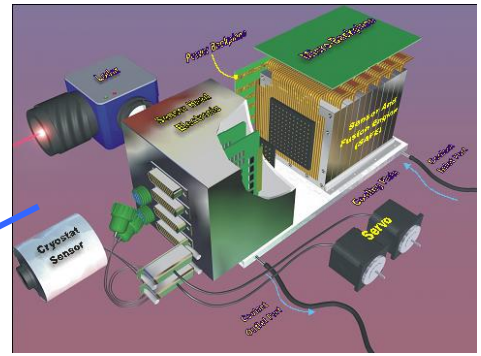
Flexibility, Scalability, Reliability



Instrument controller







Malleable image processor

Programmable matter

Programmable wiring

Analog systems

Digital systems

Traditional Computers

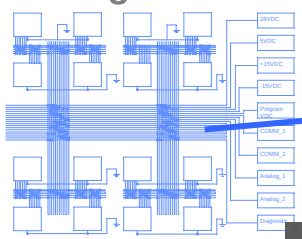
FPGAs

Programmable Analog arrays

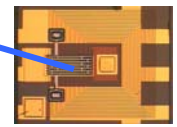
Programmable microwave

configurable power

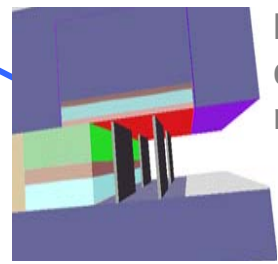
configurable mechanism



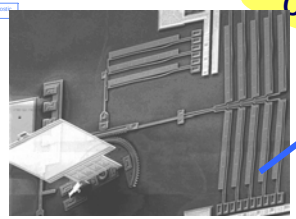
Wiring manifold



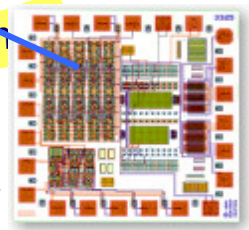
RF MEMS



Non-volatile digital memory



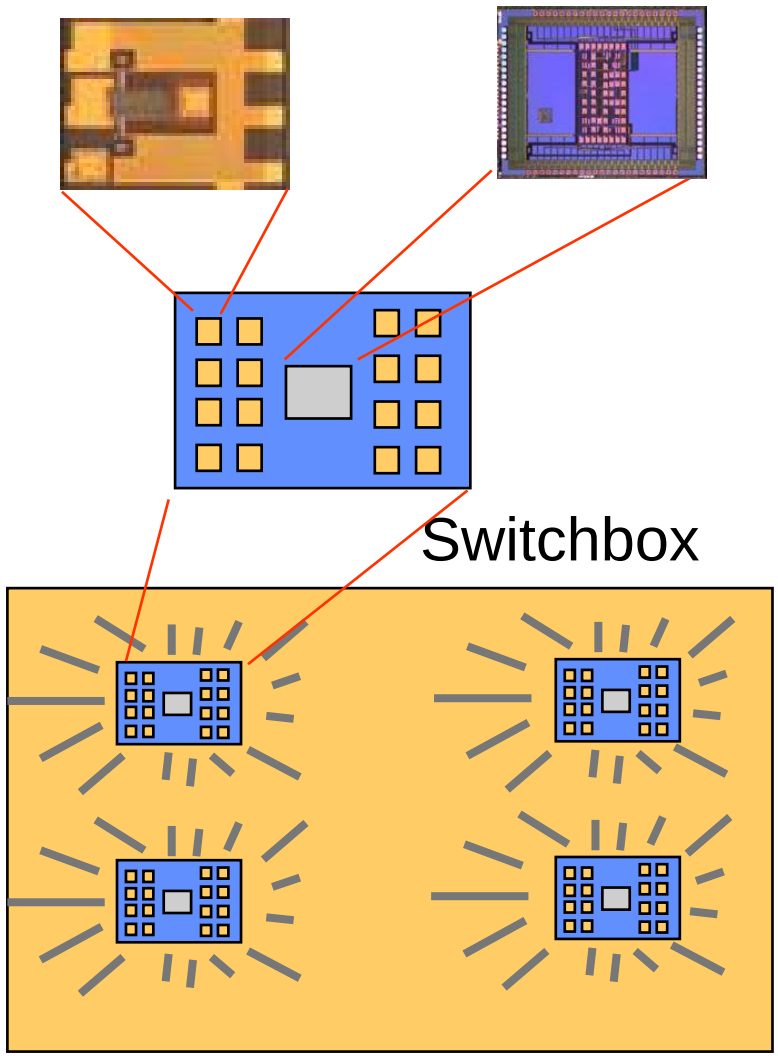
MEMS actuator



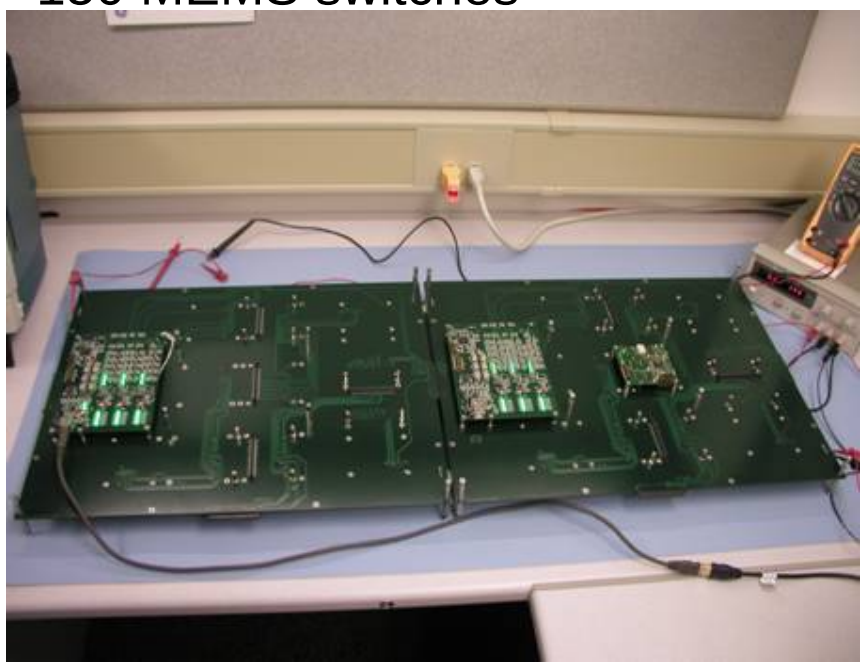
Mixed signal tile array

The Incubator of New Technology with Established Tech Transitions into Other Branch Programs

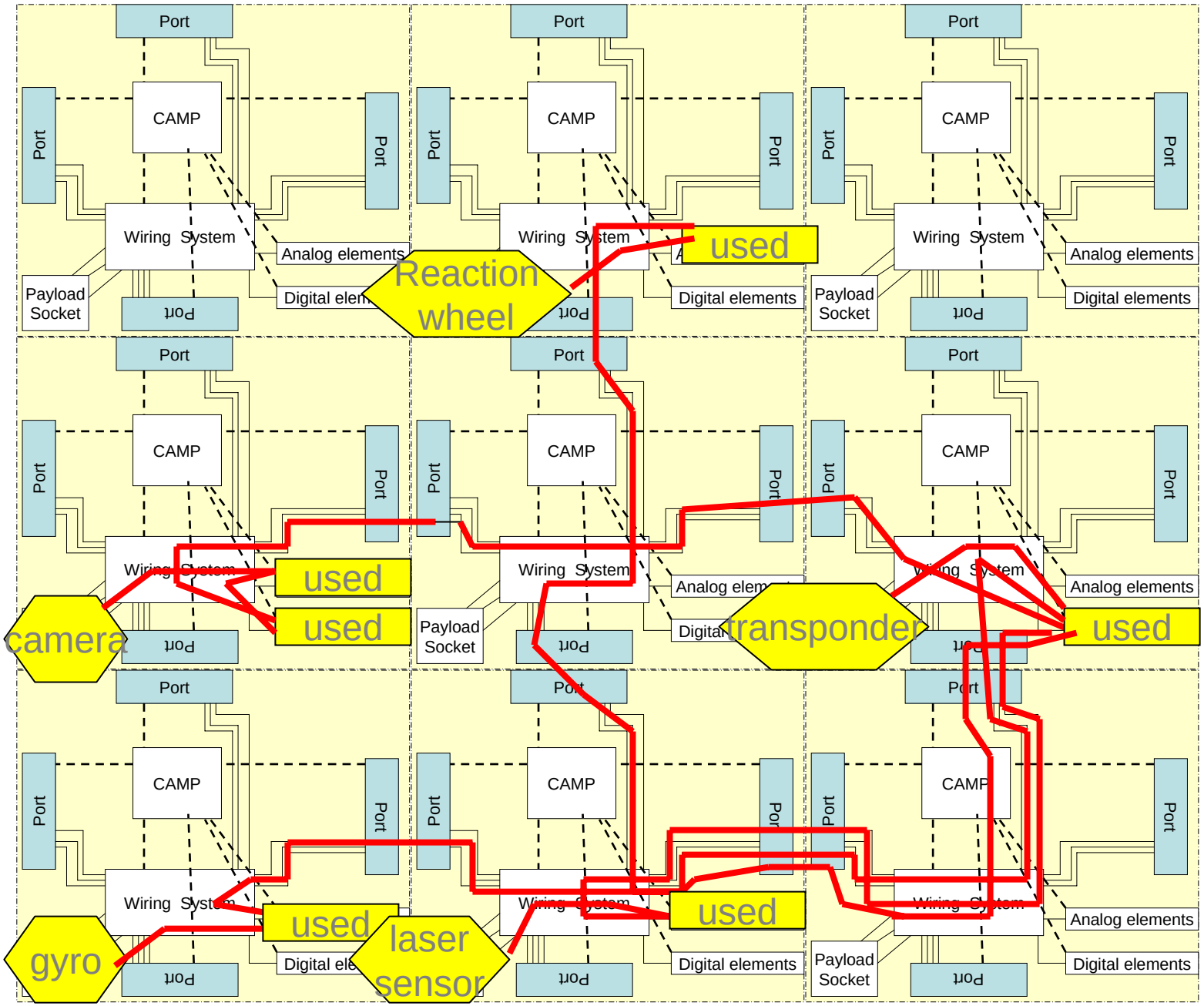
Adaptive Manifold



- Objective: Develop important building block for adaptive wiring harness
- Results to date: Demonstration of Adaptive wiring Manifold with > 150 MEMS switches



Modular, Building-block Spacecraft



Plug & Play Components
Black Box Objects

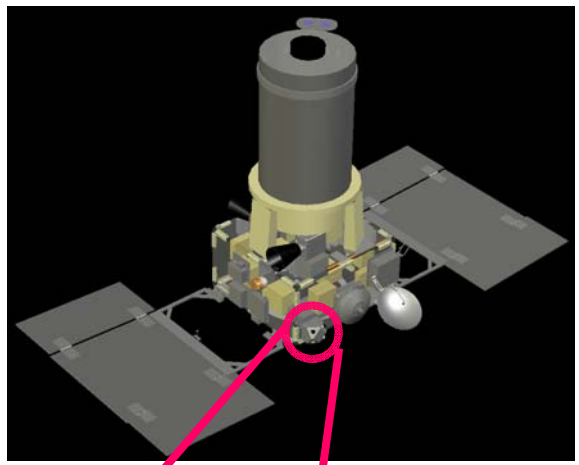
“platform”

plug-and-play component

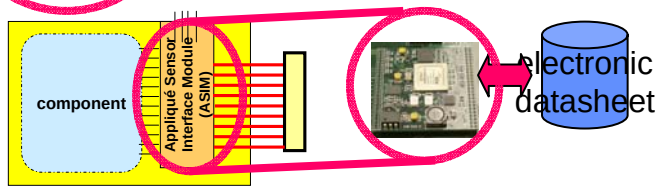
driver

USB interface chip

“platform”



plug-and-play component

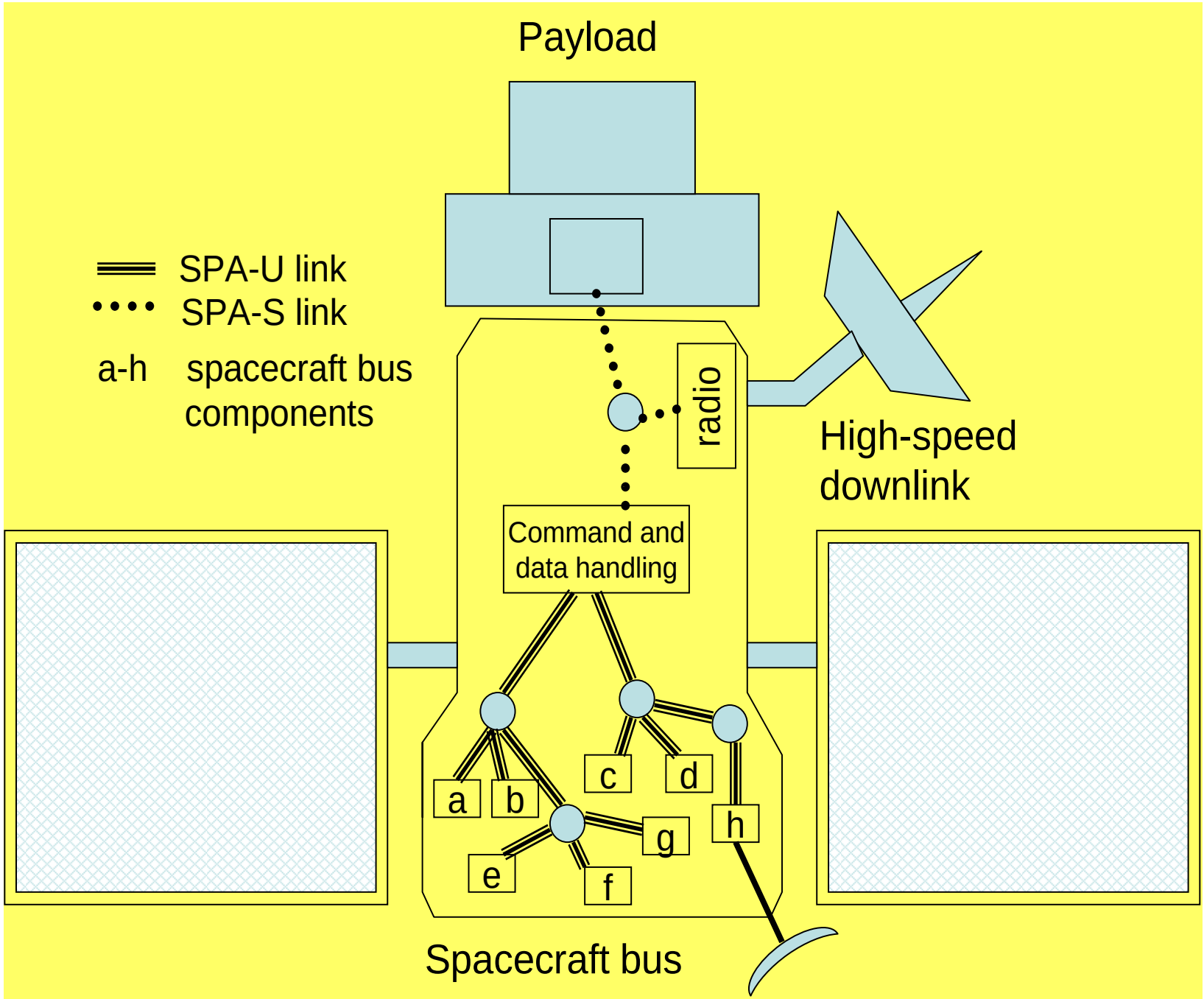


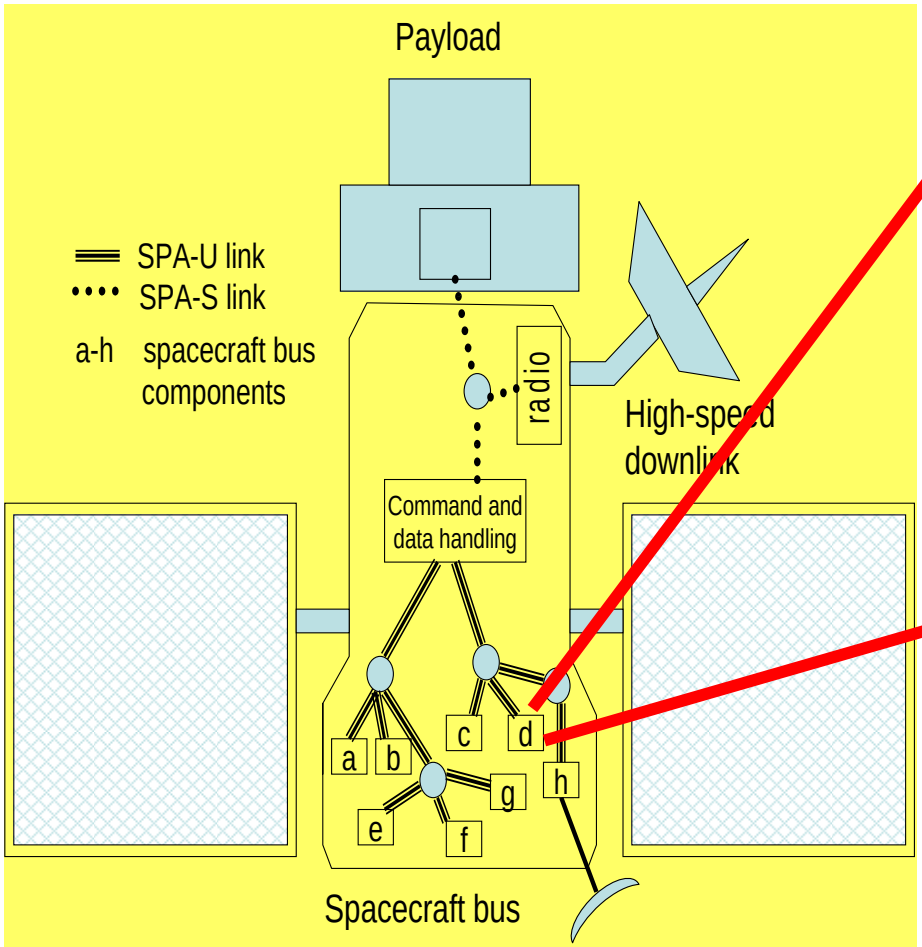
interface module

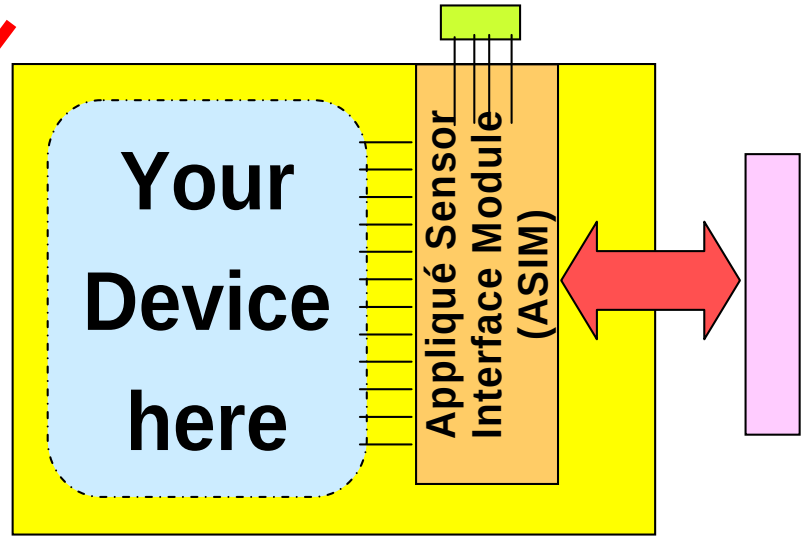
What is Plug-and-play

- Plug-and-play is centrally based on smart components
  - **Every contains built-in electronic datasheet = xTEDS (XML-based electronic datasheet)**
- Components network into a self-organized system

This approach is called "Space Plug-and-play Avionics"

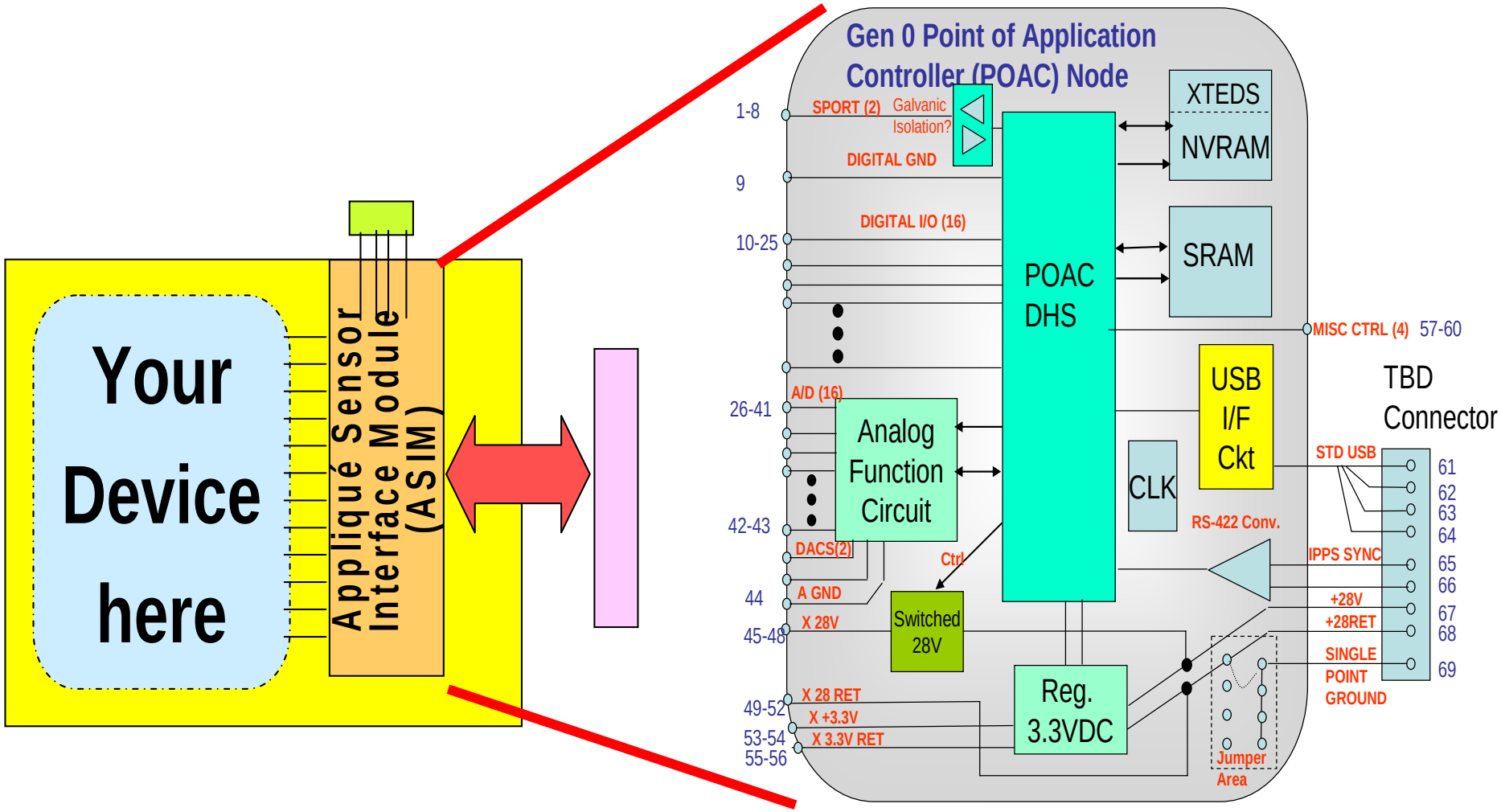

Payload
SPA-U link
SPA-S link
a-h spacecraft bus components
radio
High-speed downlink
Command and data handling
a
b
c
d
e
f
g
h
Spacecraft bus



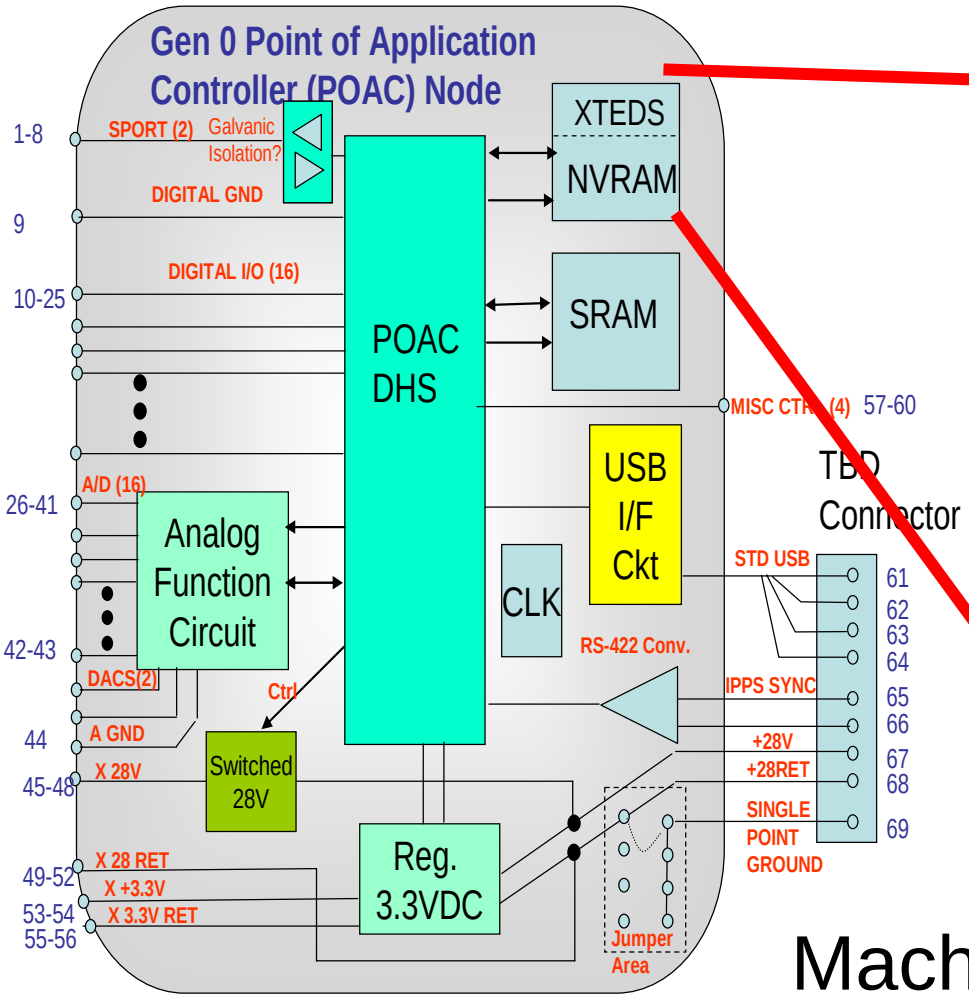


Plug-and-play components – black-box objects

Smart Interface: the Applique Sensor Interface Module (ASIM)



Electronic Interface Descriptions

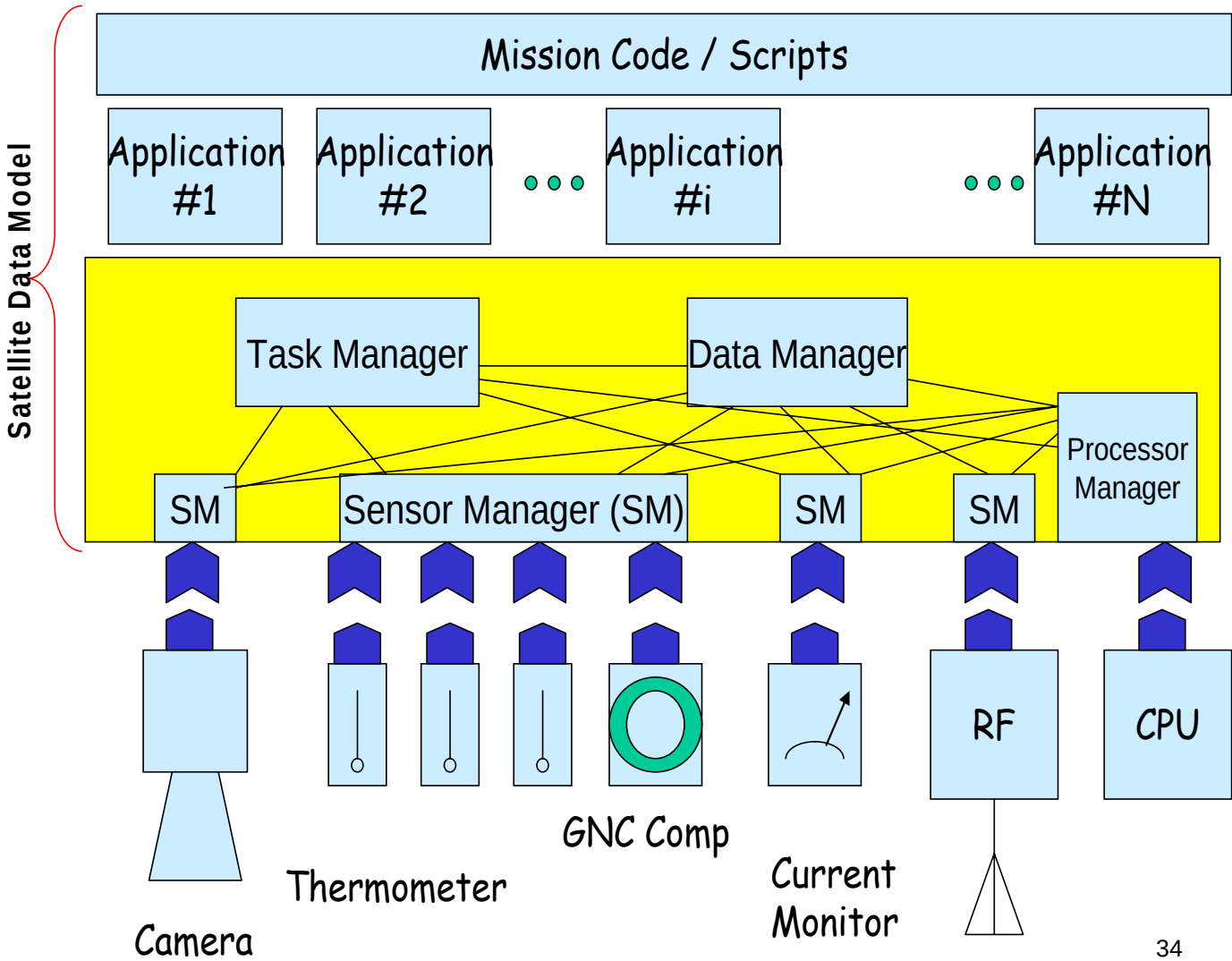


XML-based Electronic Data Sheet (xTEDS)

Machine-negotiated interfaces

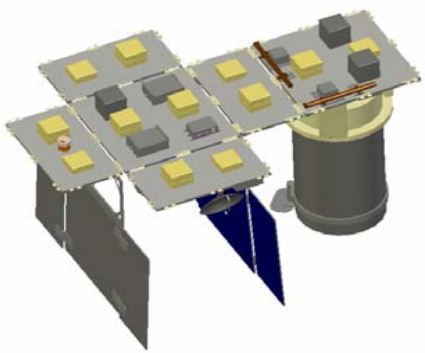
Plug-and-play Software Layered Model

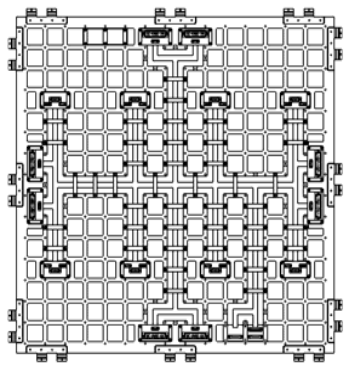
"Satellite data model" (SDM) created to address mechanisms for making software "plug-and-play" aware

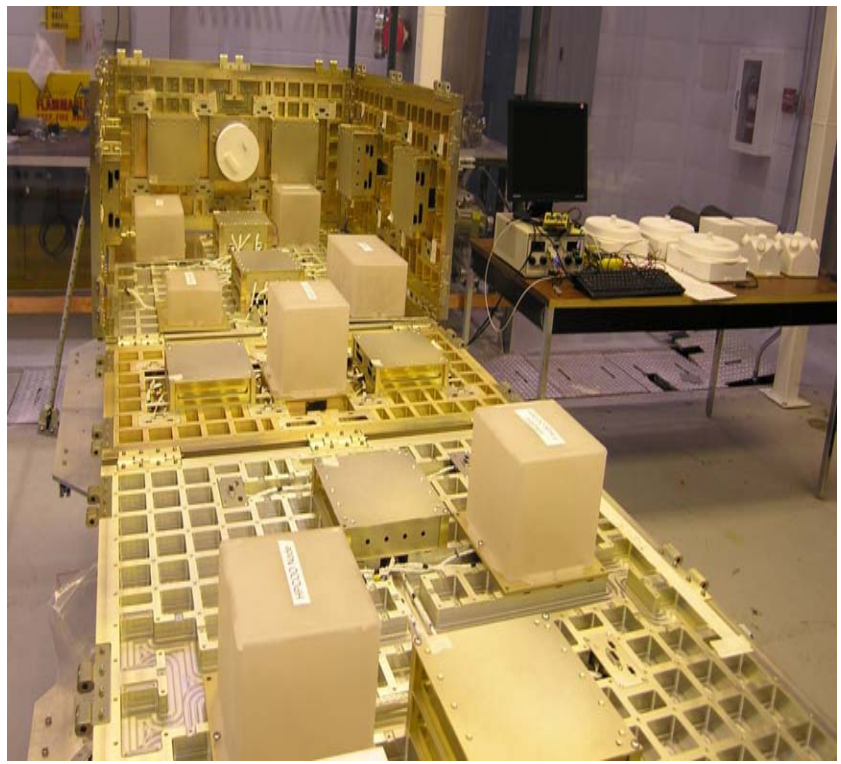


Modular Concept Bus

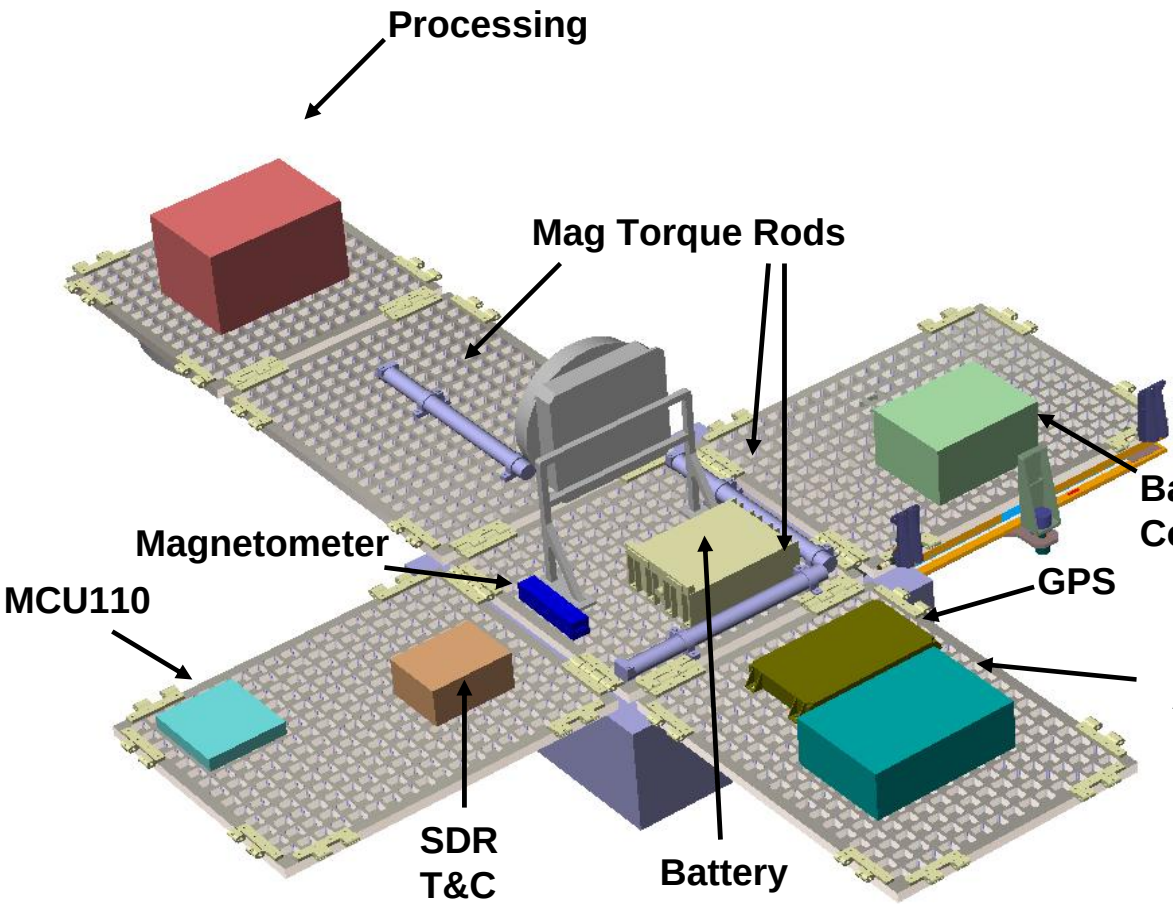
- Logically extends ideas of plug-and-play to the rest of the satellite
- Standardized Mounting Grid (2” oc, move to 4cm)
- Regular SPA locations
- SPA pre-integrated in panels
- Panels open for easy access

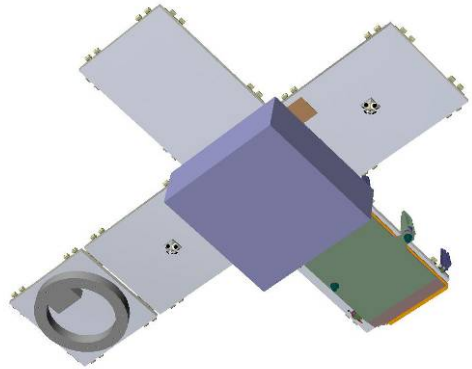


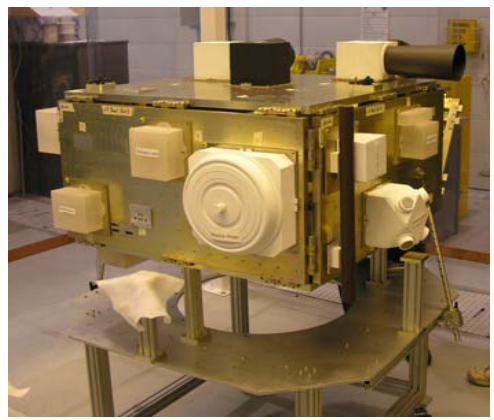




Rapid Assembly, Integration, and Test







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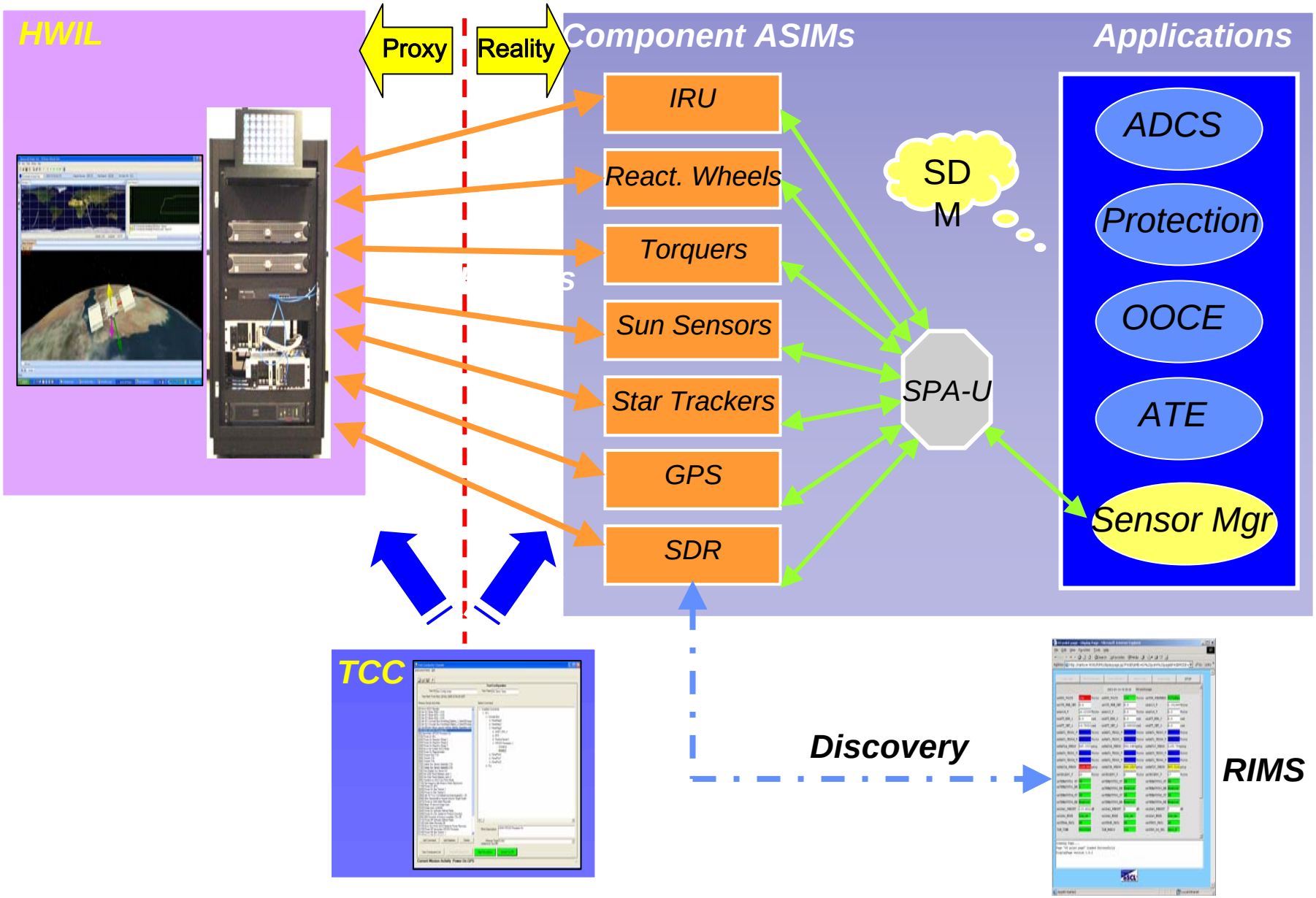

Observations

- Improve wiring problems through a few simple principles
  - Intelligent modularity
  - Scalable serial interconnect (>> 1Gbps)
- Not all wire is needed all the time
  - Reconfigurable wiring approaches
- Wireless is an encouraging prospect for reducing a lot of the wiring manifold
  - Hard to deliver much power without wires
  - We are considering for support wiring subsystems such as the test bypass networks in SPA
- Distributed Power Management could be a complementary approach

Summary

- Packaging is driven by problems of interconnection
  - Spacecraft, aircraft, etc. are “large packages”
- Nature of wiring seems to follow a scale-free model
  - Not purely a random network
- Can’t fight nature, employ a number of techniques to deal with the “war on wires”
  - Modularity (enforces simplicity in interfaces)
  - Reconfigurability (allows repurposing of interconnections)
  - Wireless (allows reduction of wiring manifold)
- Understanding wiring demand and nature of complex systems drives pursuit of intelligent strategies to combat growth in the wiring manifolds of aerospace systems