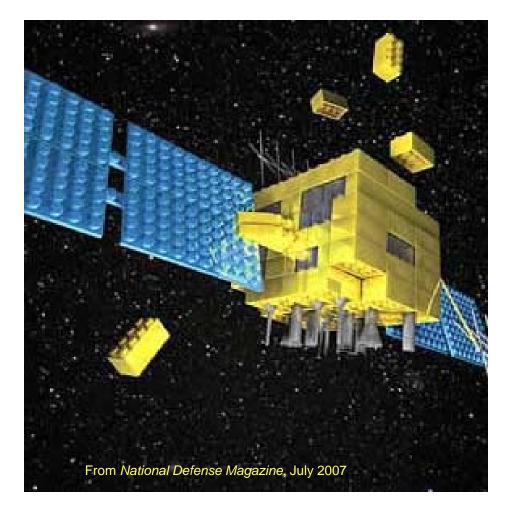
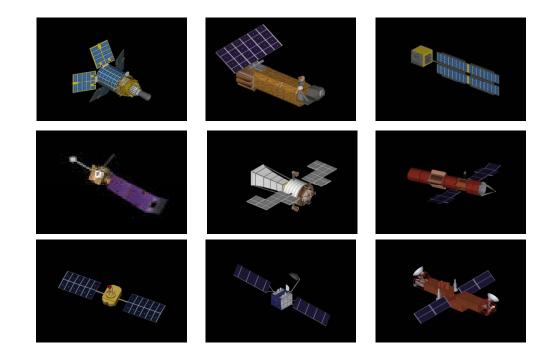
### The Six-Day Spacecraft: Creating a Plug-and-play approach for aerospace systems



James Lyke Air Force Research Laboratory 23 September 2008

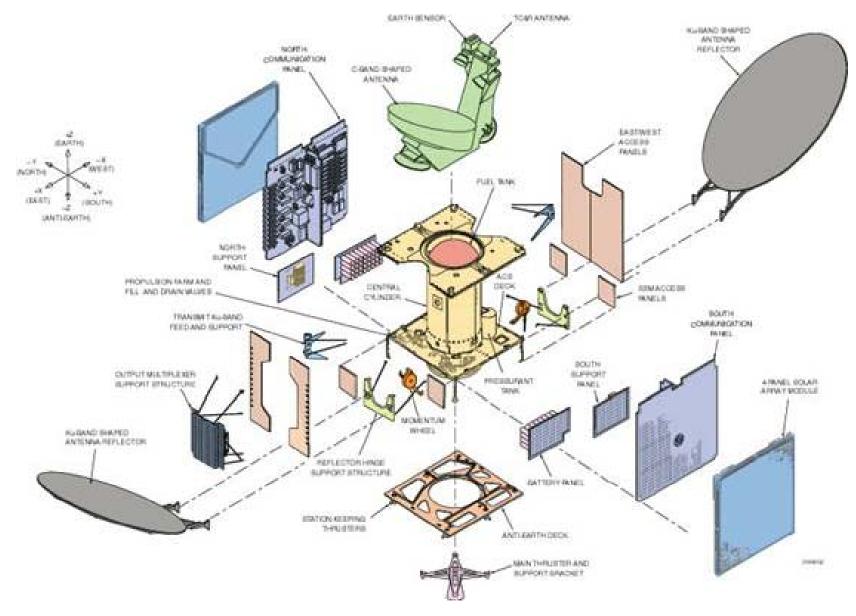
# **Problem Formulation**

• Create a spacecraft in less than one week



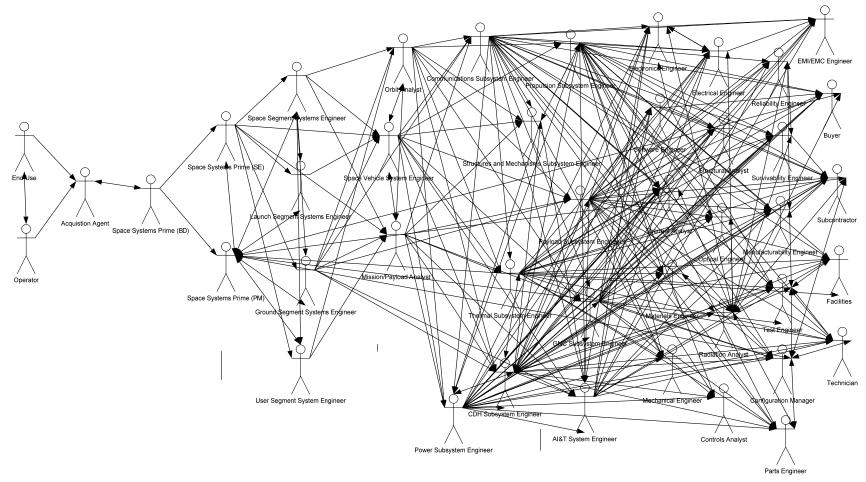
# Days Instead of Years....

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



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

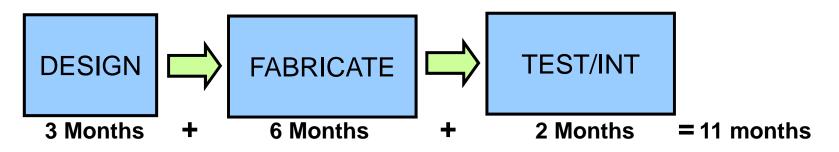
# The "Marching Army"



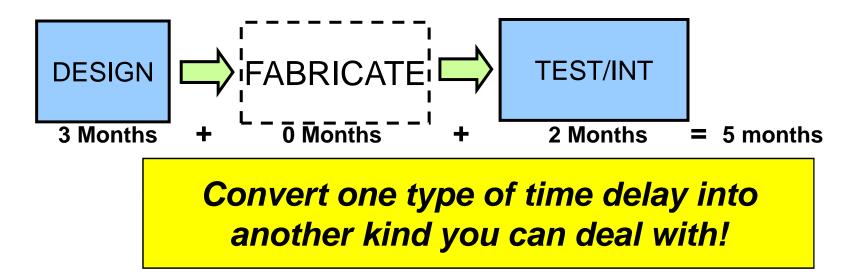
Courtesy of Michael Enoch, LM

### Beating time delay – an example

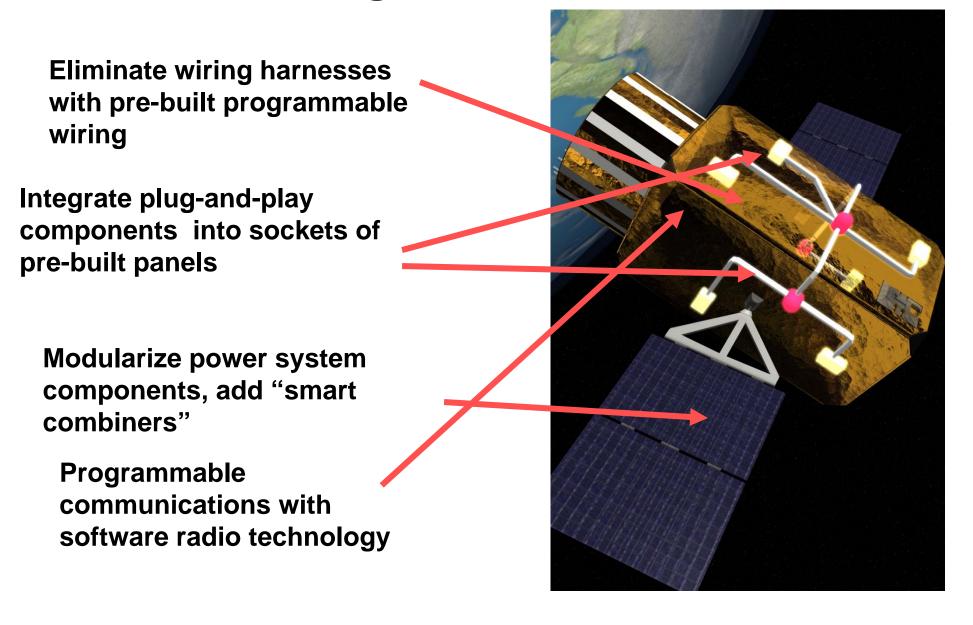
**Integrated Circuit (IC)** 



Field Programmable Gate Array (FPGA)



#### Field-Programmable Satellite Made with Field-Programmable Parts?



# A Scalable Technology for Plugand-play Systems

- Satellite Design Automation (SDA)
   The metaphor of the "push-button toolflow"
- Space Plug-and-play Avionics (SPA) components / technologies
  - Interfaces (SPA-U and SPA-S)
  - Appliqué sensor interface module
  - XTEDS
  - Satellite data model
  - Test bypass

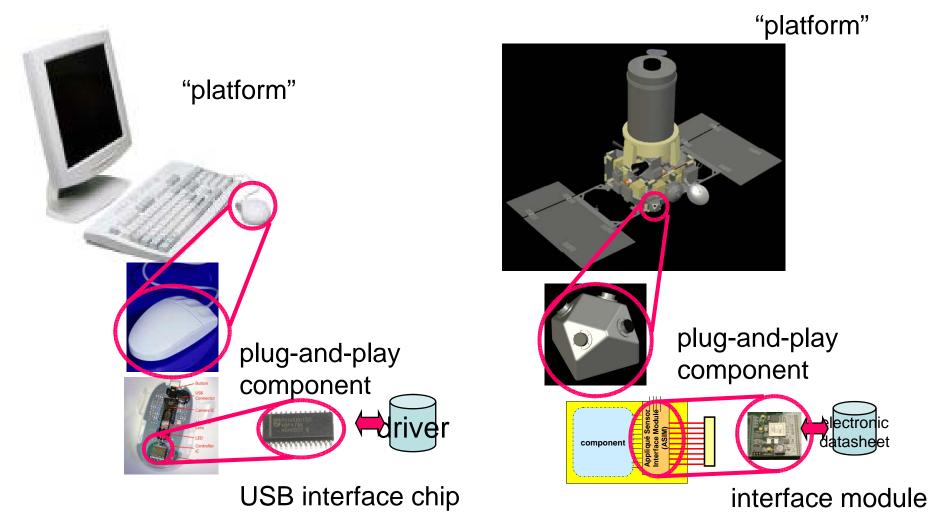
#### **Ultra-Rapid Upfront Specification Generation: Mission Driven Tools** Mission Goals and Requirements **Component Capabilities** Connections Component 3. 2. Icons - 124 - 8 / 11 新聞道 山 - 2 - 3 - 三 - 三 - 三 - 三 -AUTO-SPACEutomatic **Drag & Drop Design GENERATE** CRAFT Correction *'EVERYTHING"* **PROFILER** -Ver Denter Harden Hard ate \_ f cation P Ť Engine + - 100 07 CATEGORY RULES (1. predCategory( catidReferenceFrame ). **Design Verification Rules** predElementOf( catidReferenceFrame, cativeferenceFrame ) predCategory( catidCoordinateSystem ). entOf( catidCoordinateSystem, catidCoordinateSystem) MISSION ULES **Performance Modeling** CAPTURE dlEnvironmentObject ). predElementOf( iidlEnvironmentObject, catidEnvironment ) predInterface( iidlMomer COMPARE predElementOf( iidlMom SIM VS. THE COMPONENT RULES predComponent( clsidCE ORIGINAL predElementOf( clsidCEa predElementOf( clsidCEa fncln( iidlEnvironmentOb **MISSION**

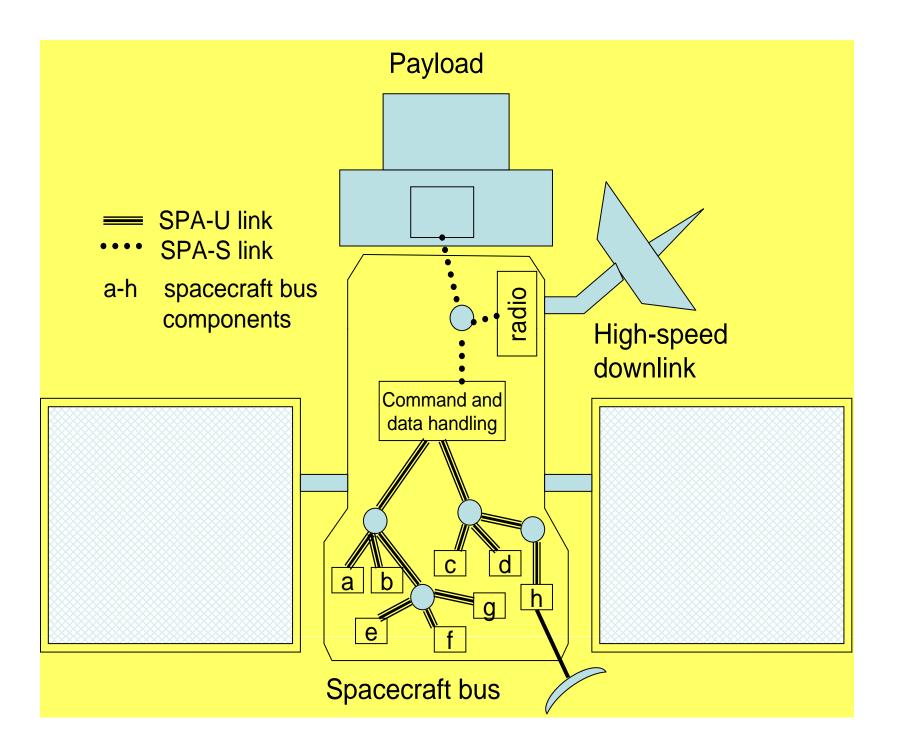
# What is Plug-and-play

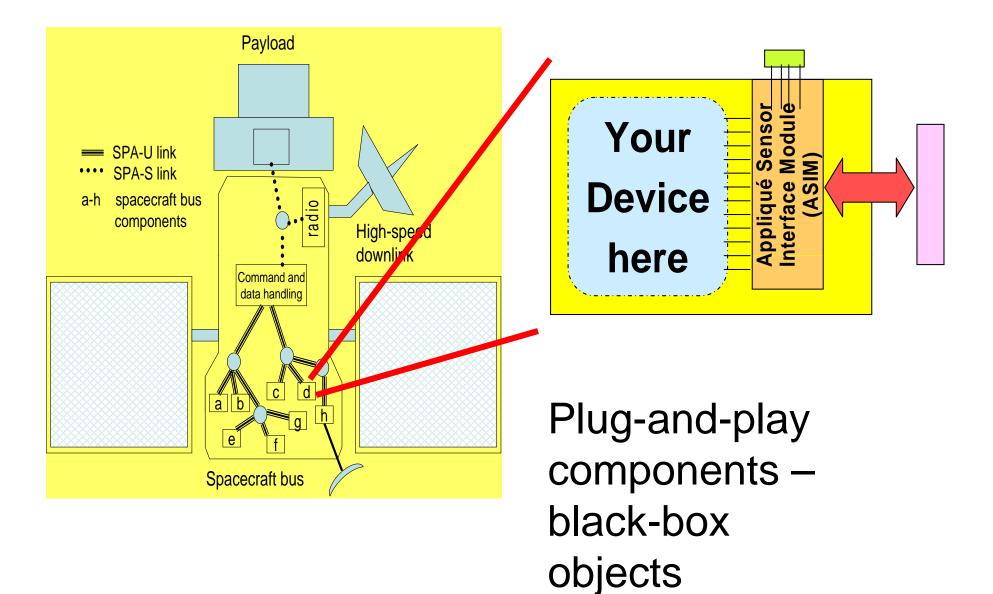
- Plug-and-play is centrally based on smart components
  - Every contains built-in electronic datasheet = xTEDS (XML-based electronic datasheet)
- Components network into a selforganized system
   This approach

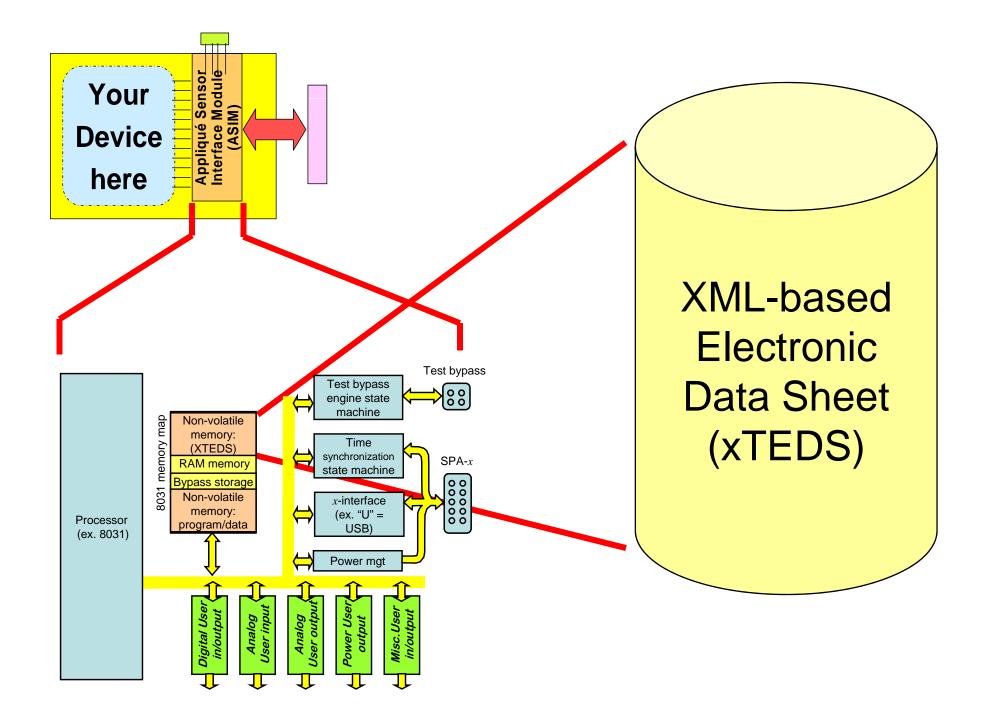
This approach is called "Space Plug-and-play Avionics"

### Plug-and-Play Components Black-Box Objects

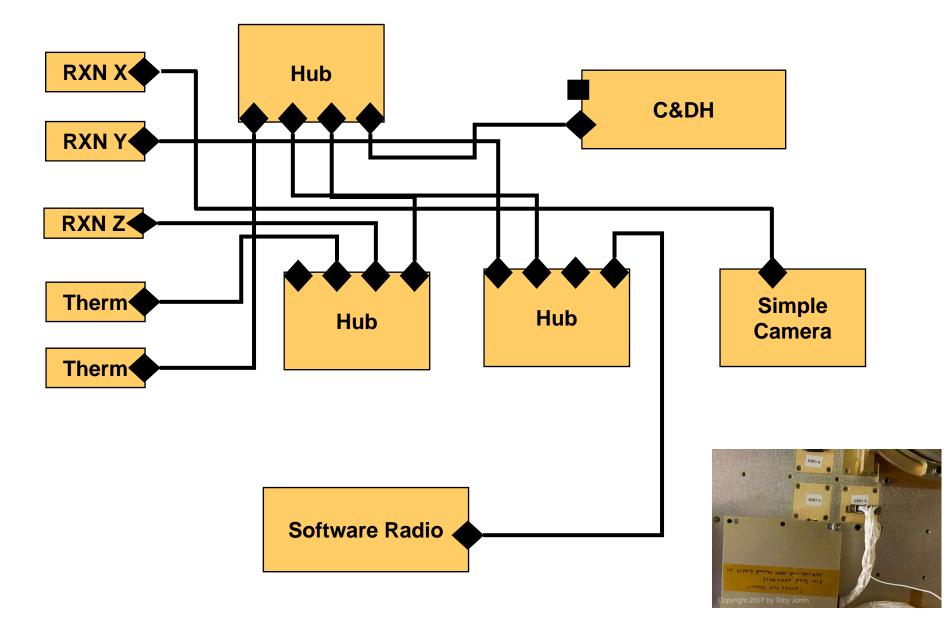


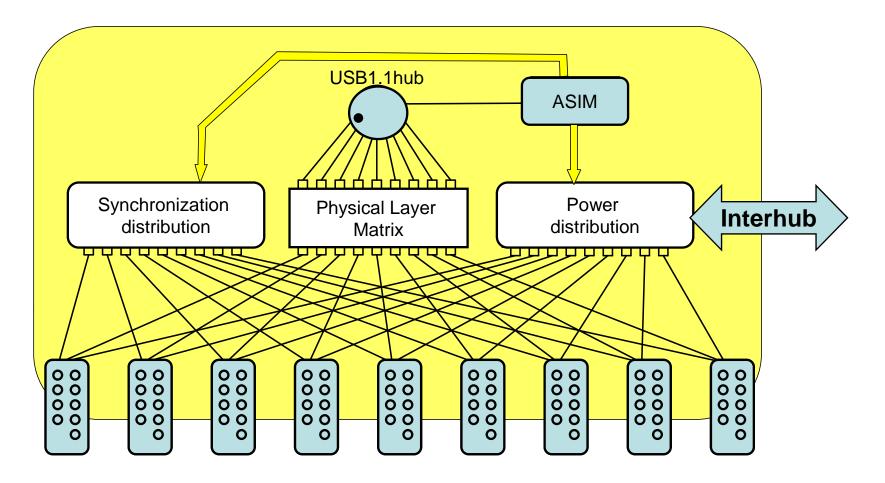


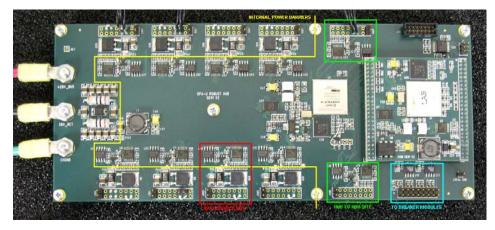




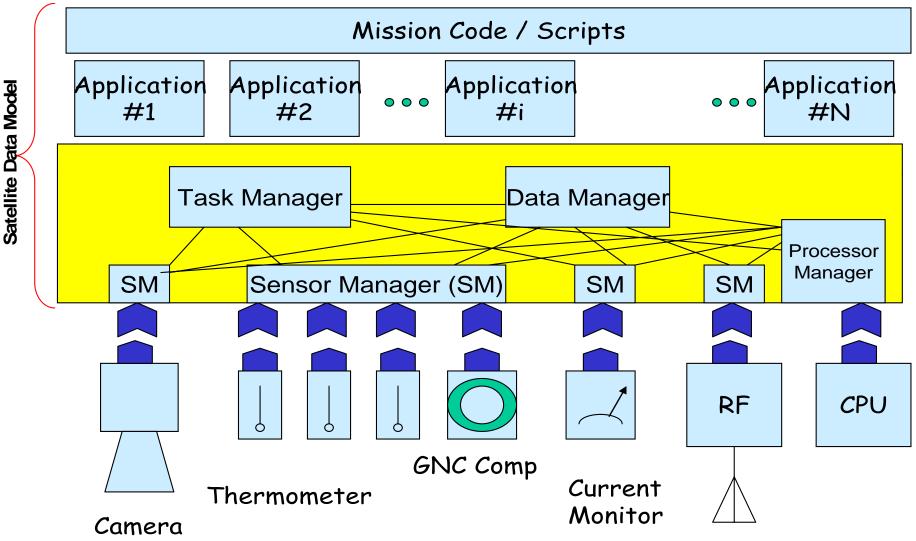
#### SPA Networking with SPA devices / hubs



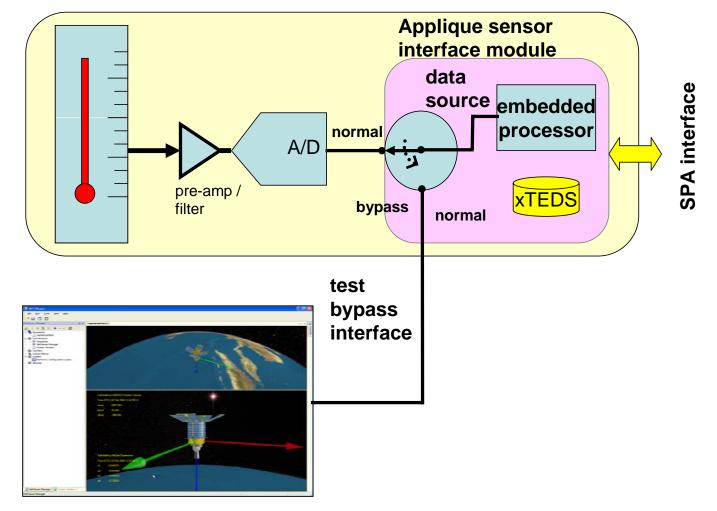




#### The Satellite Data Model (SDM) – Building Awareness into Plug-and-play



To simplify the testing of complex systems, a "test bypass" feature is integrated in the SPA plug-and-play interfaces. Test bypass allows an external control (simulation) to provide substituted values during test, similar to the test/debug methods used in developing software. Test bypass is particular useful in cases where an actual test involving a device's native sensors and actuators is impractical.

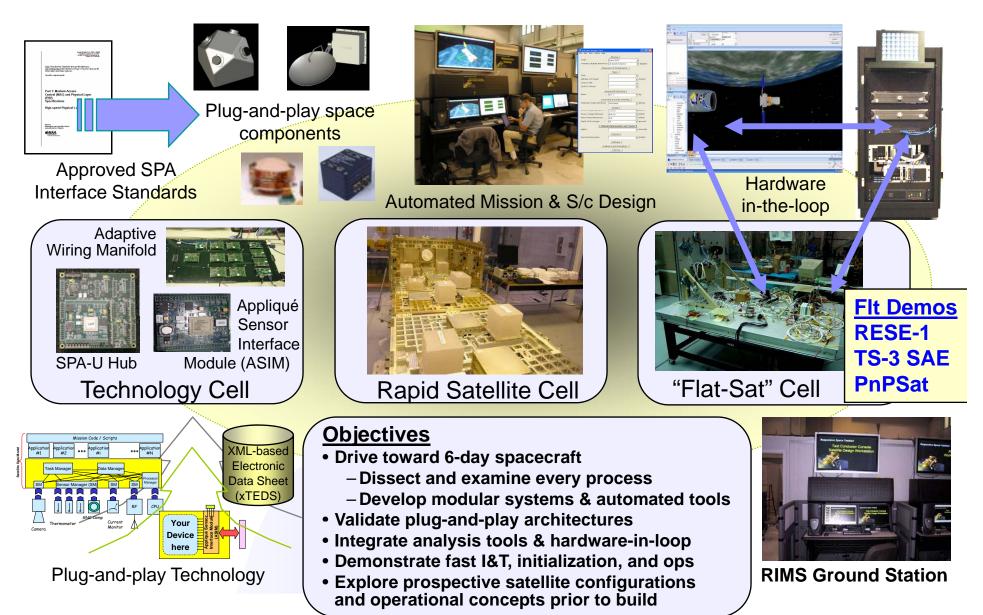


SPA (plug-and-play) thermometer

# Maturation / Flight Projects

- Ground validation Responsive Space Testbed
- Current flight projects
  - RESE (sounding rocket) (completed)
  - SAE (part of TacSat 3)
  - PnPSat
- Prospective
  - TacSat V
  - PnP Nanosatellite

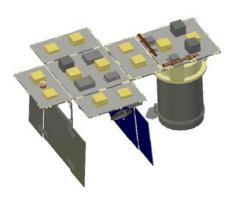
# **Responsive Space Testbed**



# Modular Concept Bus

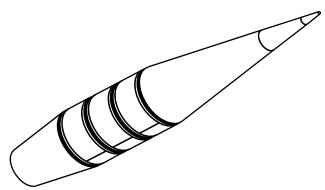
- Like the Detroit "concept car"
- Logically extends ideas of plug-and-play to the rest of the satellite





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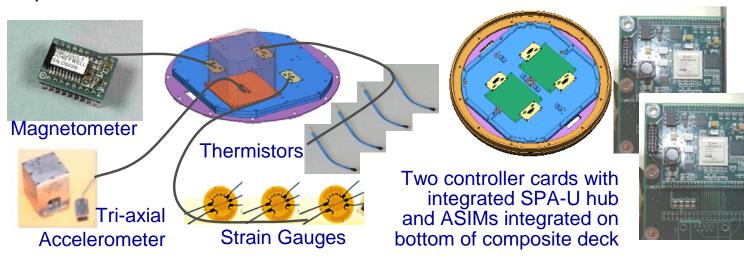
### Re-Entry Structures Exp't I (RESE-1)



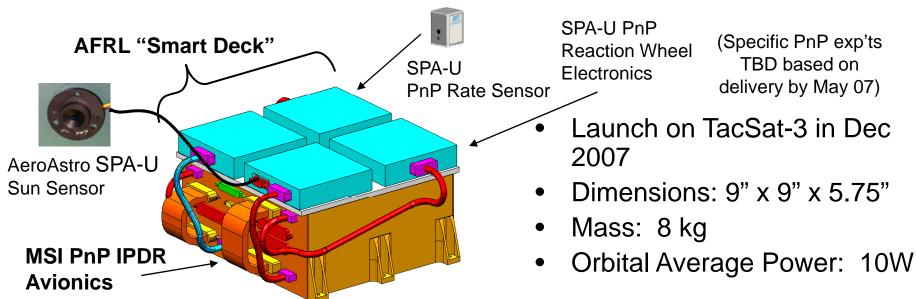
RESE-1 Plug-and-Play Experiment on dedicated composite deck with 4 SPA-U spacecraft sensors: **RESE-1** Suborbital Flight Experiment

- Sounding Rocket: Single stage Terrier
- Launch Site: White Sands
- Launch Date: Sept 2007
- Max Altitude: ~ 250,000 ft
- Duration above 90,000 ft: ~100 sec

SPA hardware integrated into controller cards and configured for space in 4 months

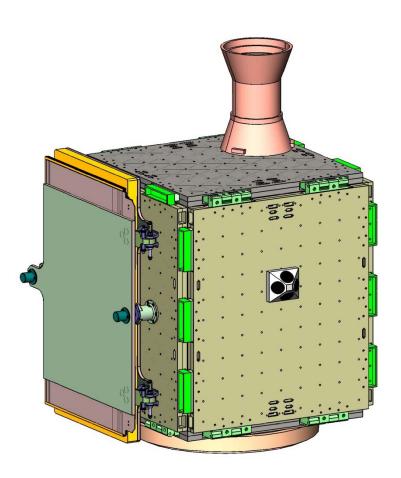


#### TacSat-3 Spacecraft Avionics Experiment (SAE)



- Smart Deck with SPA-U host, 4 SPA-U ports, and data handling system
- Parallel PnP capability using MSI's Intelligent Power & Data Ring (IPDR) with multiple processing nodes for redundancy
  - Spacewire/SPA-S link between Sensor Processor and C&DH for backup downlink capability of HSI data
- SPA-U PnP experiments
  - Reaction wheel electronics, rate sensor, memory stick data storage, AeroAstro Sun Sensor, or other (selection in progress)

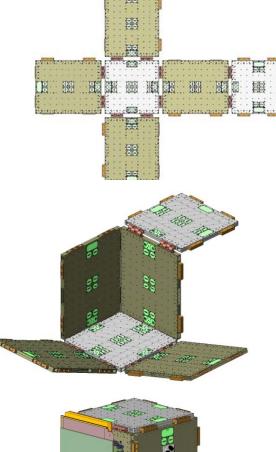
# Plug-and-play Satellite (PnPSat)



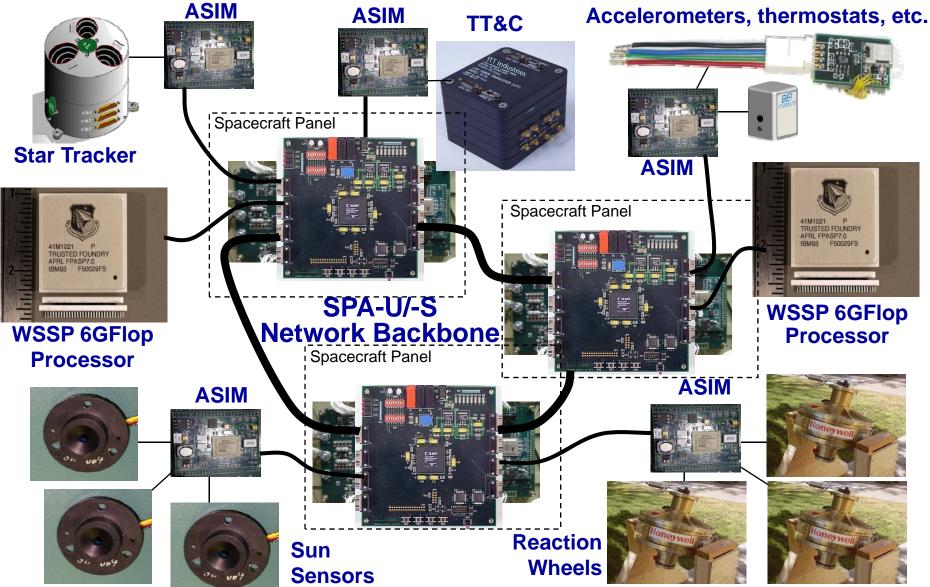
- First spacecraft ever built entirely on PnP principles
  - Decentralized, scalable computation
  - Use of satellite data model
  - All components (even panels) are SPA devices
  - up to 48 mounting sites
- Ambitious development schedule
  - Targeting flight in 2009

# Configurations of PnPSat

- PnPSat bus can be easily changed to various configurations to support requirements for different stages of the project
  - Flatsat configuration
  - Assembled configuration
  - Other configurations possible
- Panel-to-panel joints are pinned to allow panels to be rotated from horizontal (flat) to vertical (folded)
  - Securing hinged joints with precision pins
- Individual panels or sets of panels can be integrated and tested in parallel before final assembly

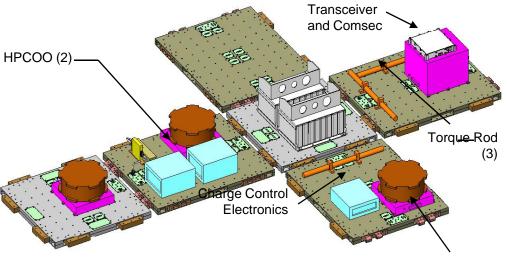


# PnP Elements Enable Avionics Network

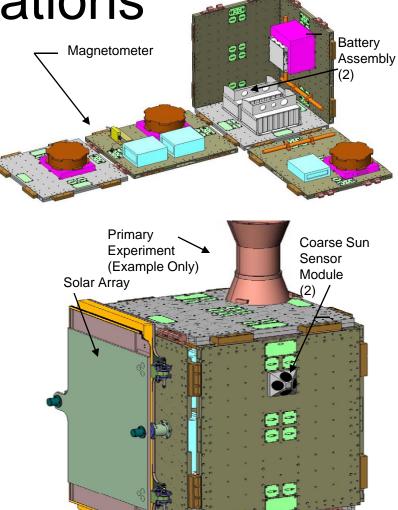


# Component and Experiment Accommodations

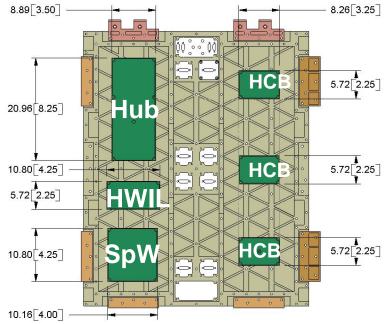
- A full complement of PnPSat components shown
  - By recessing electrical infrastructure and harnessing, we significantly increase flexibility for component and experiment mounting
  - Initial version of PnPSat may have fewer spacecraft components than the version shown

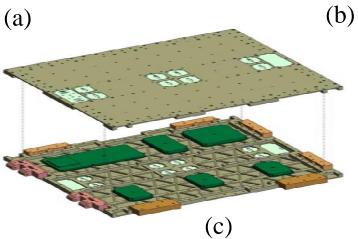


Reaction Wheel and Electronics (3)

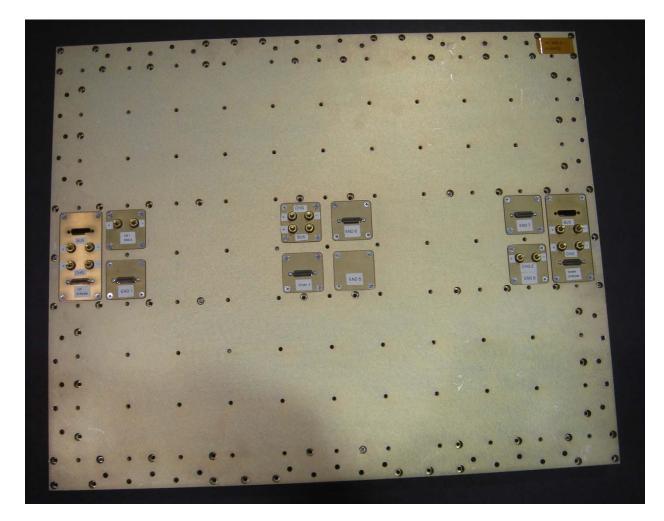


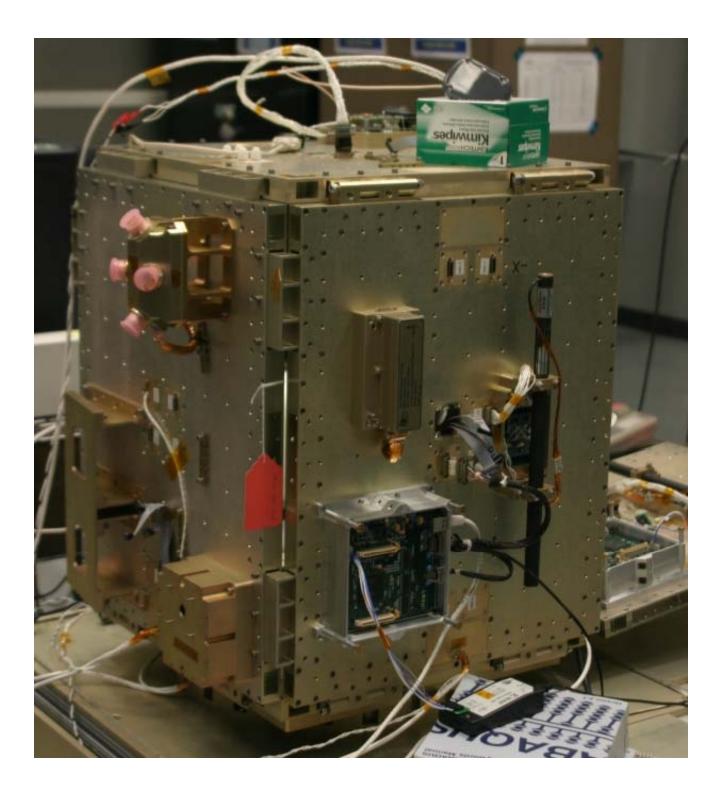
### Encapsulation (complexity hiding)





### Encapsulation (complexity hiding)



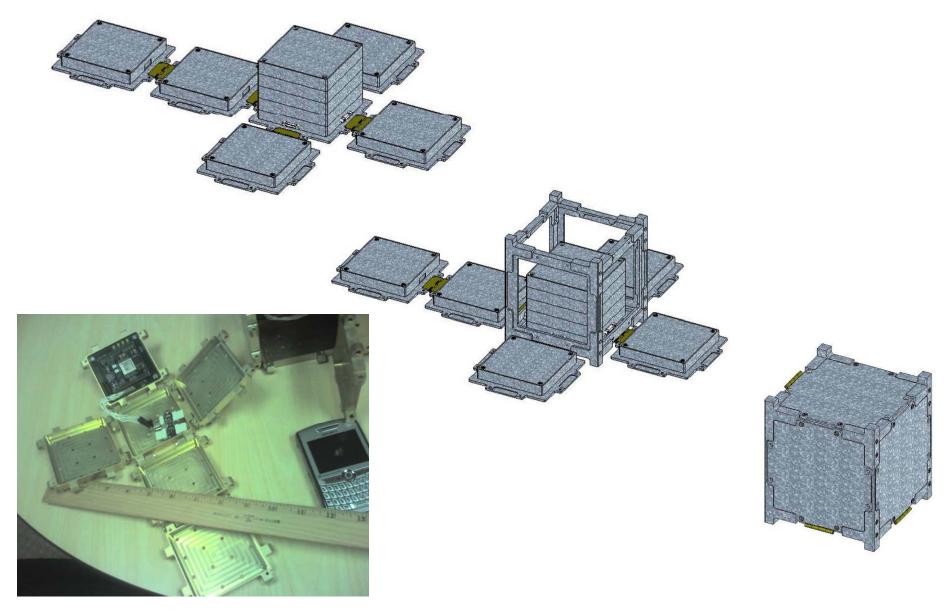


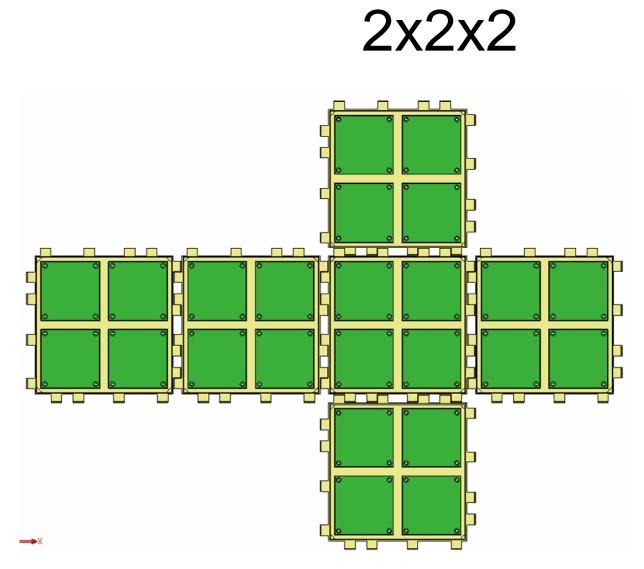
# Miniaturization - the "nano"

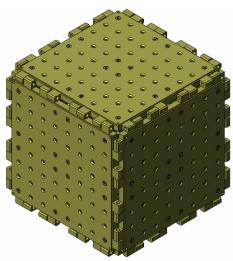
- Targeting PnP platforms as small as cubesats (100mm)
- Supports increased payload mass fraction and creation of PnP nanosatellites
- Compact nanosat modular form factor (NMF)standard (70mm x 70mmx12.5mm)



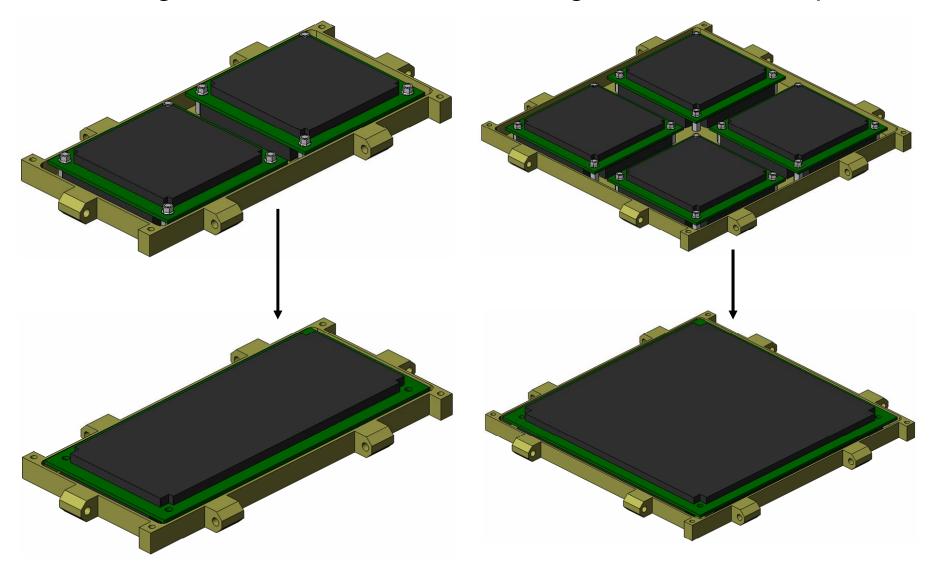
### Frame and Module







#### Larger Geometries Feature: Larger Board Envelope



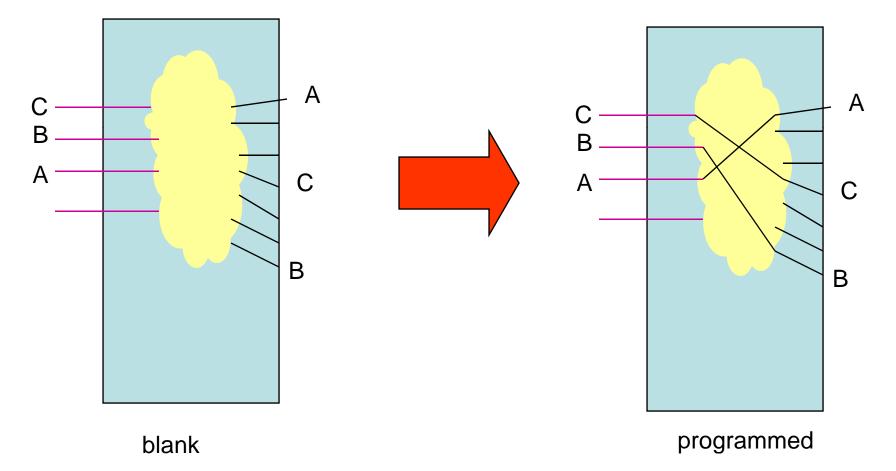
# **Future Directions**

- SPA evolution (backward-compatible improvements)
- High Performance Computing On-Orbit
- Software-definable radios ("Modular comm")
- Push-button toolflow (PBTF) vision
- Power systems
- Thermal systems: improved isotherms, coarsegrain configurable thermal management
- Application development
- Miniaturization

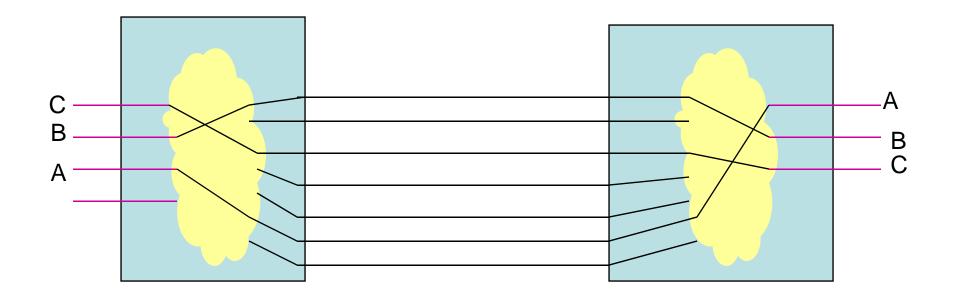
# Adaptive wiring manifold

- Wiring harnesses take a long time to build
- Adaptive harnesses can be pre-build and programmed in minutes
- The adaptive wiring manifold complements and extends the utility of the SPA concept by allowing other special types of electrical connections (e.g. analog, rf) to be programmable managed in a "plug-andplay" manner

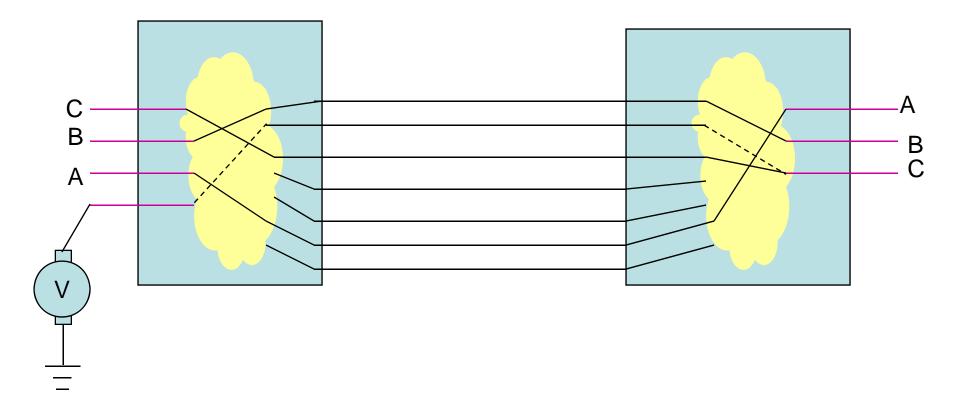
#### Adaptive wiring allows terminal connections to be set under software control



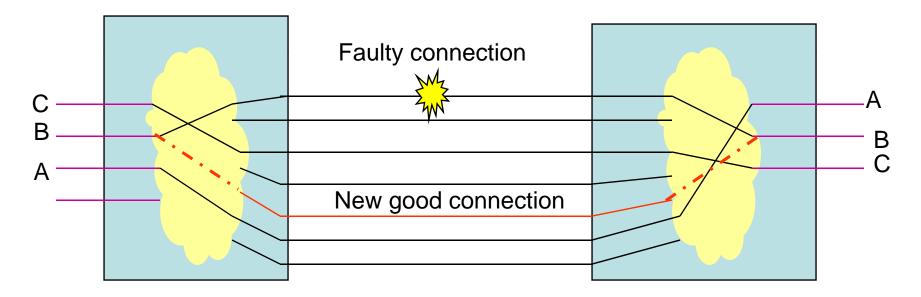
Adaptive manifolds can be built into panels or boards, which can flexibly assembled in different ways and programmed in ensemble to yield the desired connection patterns



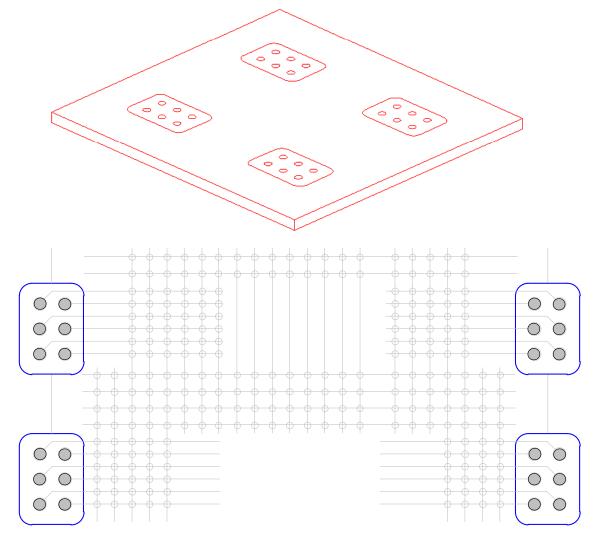
Temporary probes can be inserted and "dissolved" when no longer needed. In this case, we use the manifold to set up a temporary connection to check a possible problem with terminal C on the right panel



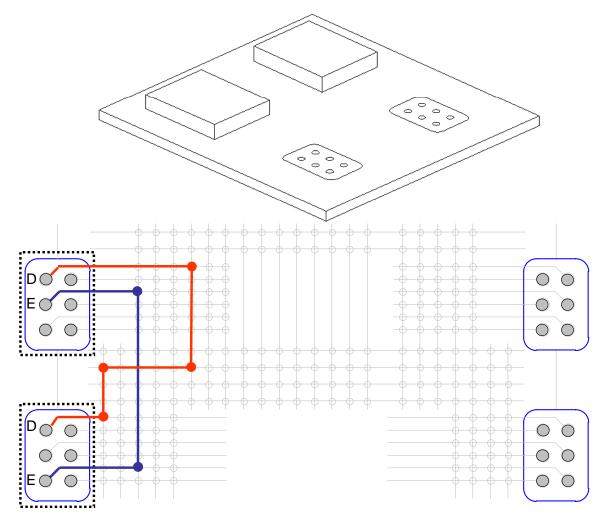
Adaptive manifolds can be reconfigured around defects or faults. In this case, we circumlocute a fault affecting "B" by reprogramming the manifolds in two panels



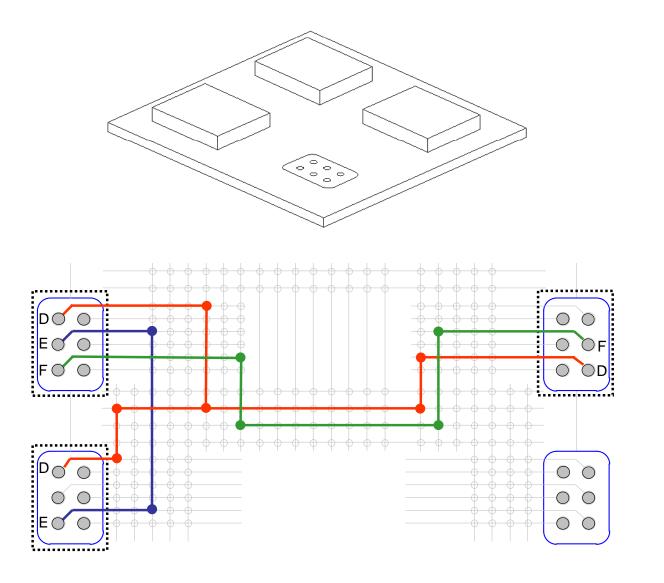
The physical embodiment of an adaptive panel could employ a number of sockets. The internal construction is at one level merely a series of wires (straight lines) and switches (hollow circles)



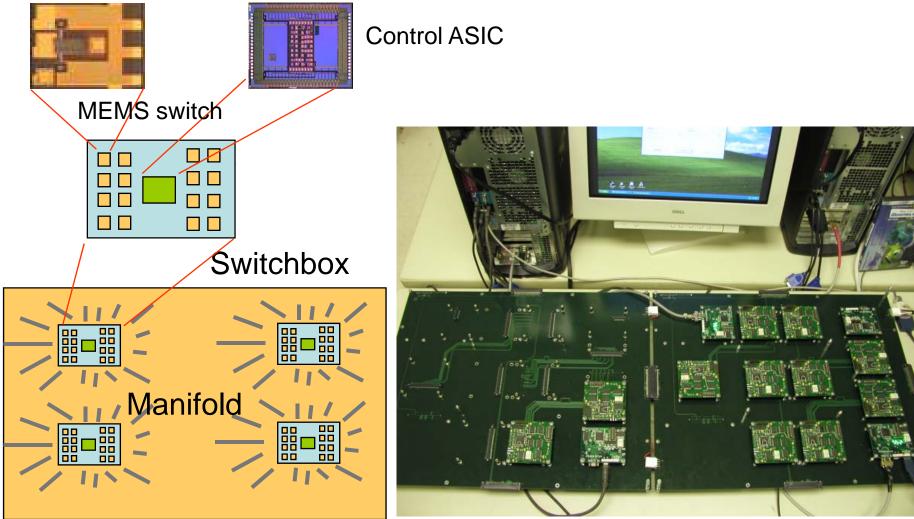
Terminals between different components plugged into the panels are formed by closing the proper switches (the paths are generally non-unique). This approach is very similar to the routing networks in FPGAs, except that the switches might be many small metal electromechanical relays or high-amperage solid state relays



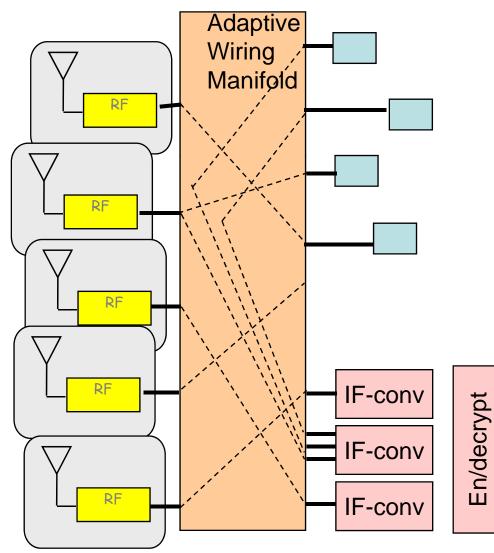
Of course, when more components are added to an adaptive panel, additional connections can be instantiated as needed



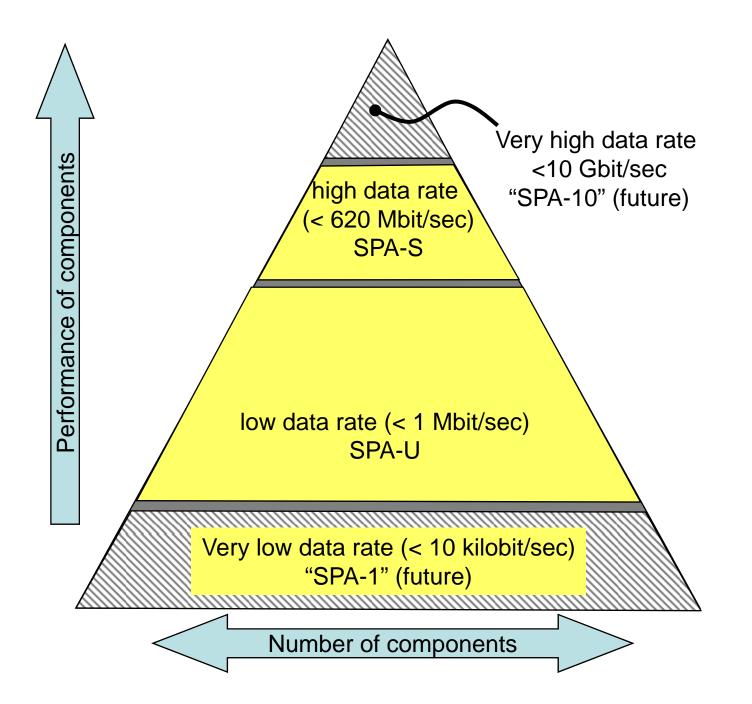
AFRL developed a simple demonstration of the adaptive wiring technology using two large "panels" and over 100 latching microelectromechanical switches,grouped into several sw. We were able to successfully move persistent (non-volatile) copper pathways from port to port

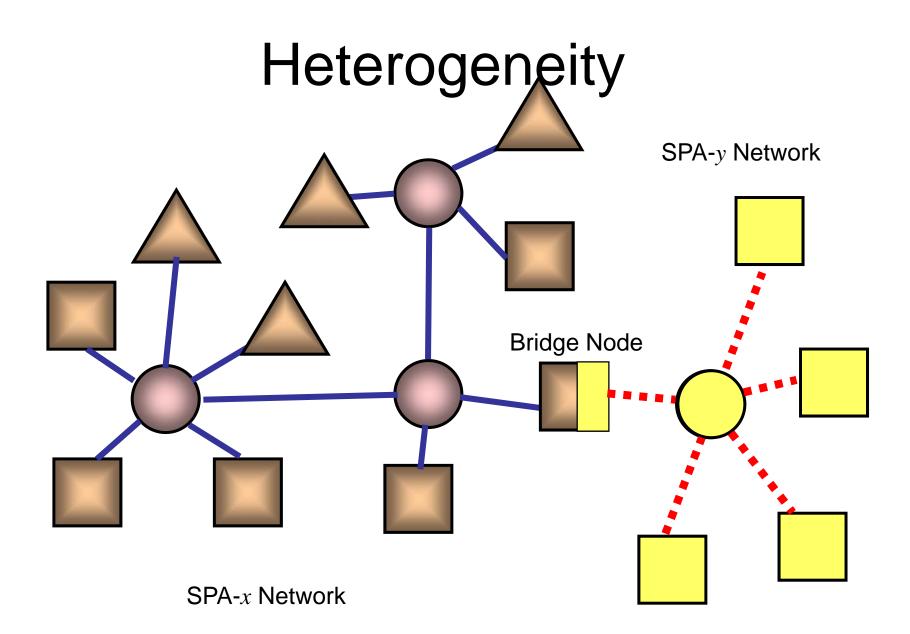


## LEGO radios (Beyond "software radio")

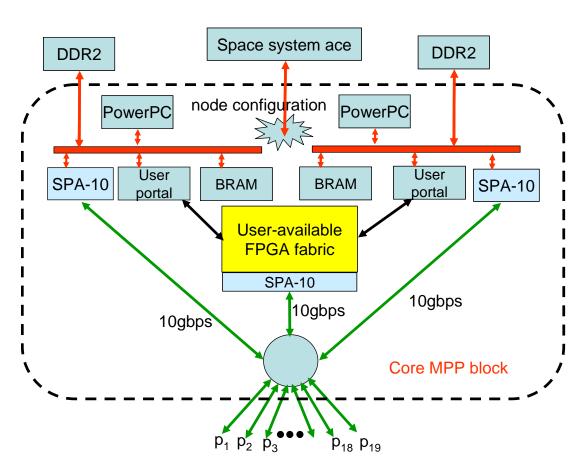


- Ability to comingle elements of a modular rf system fluidly, adaptively
- provision of more comprehensive spectrum coverage
- "Cognitive radio" (support for plug-andplay waveforms, dynamic waveforms, and adaptive configuration)



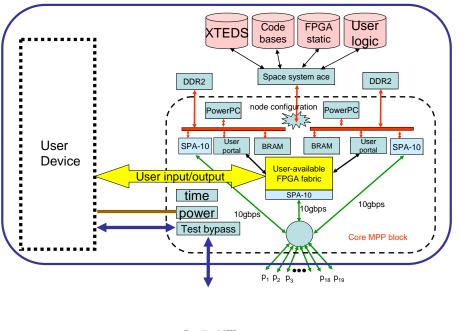


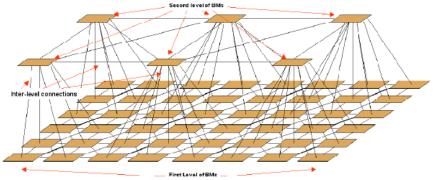
# High-performance ASIM concept for 10 gbps standard



- FPGA-based ultra-scalable network
- Each node supporting up to 20 "SPA-10" ports

## Self-scaling networks of multi-gbps endpoints





- Encapsulated highperformance nodes (up to 100Gbps bisection bandwidth)
- Scalable SPA supercomputing fabric supports grid-like connection of many SPA-10 devices
- Lower-speed SPA networks connect through bridge nodes

#### Web-based XTEDS builder

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Started Goode Boolmark C Latest Headnes Prize Ontology News A - Mongo C reate an account or  Design Corporation  C Getting Started - xTEDS Generator  C TEDS Generator - Getting Started  C TEDS Generator - Getting Started  Power Users	View History Bookmarks Iools Help		
Design Corporation          Getting Started - xtEDS Generator          xTEDS Generator          xtEDS Generator          xteps Generator          Getting Started          Beginners          Power Users          The recommended that those new to xTEDS begin by loading a sample xTEDS. You can than user           Power Users          BreadBoard_June2007 xml         FreadBoard_June2007 xml         Power Users           Power Users          BreadBoard_June2007 xml         Power Users           Power Users          CSSAssy xml         DightalS xml           BreadBoard_NoveOx00xml          CSSAssy xml         Power Users           Use the add Infuk under <i>Derice</i> (or Application) to Identify the device or application.          RytheelSingle xml           BreadBoard_NoveOx00xml         Sattwith Empty xTEDS          Start with Semple xTEDS           Sitt with Empty xTEDS          RytheelSingle xml           Sitt with Empty xTEDS          Robotiub xml           Sitt with Empty xTEDS </th <th>🔷 👻 🧭 🔝 🏦 🗋 http://www.datadesigncorp.net/xteds/app</th> <th>▼ ► Google</th> <th></th>	🔷 👻 🧭 🔝 🏦 🗋 http://www.datadesigncorp.net/xteds/app	▼ ► Google	
xTEDS Generator         xTEDS Generator         Getting Started         Beginners         A the recommended that those new to XTEDS begin by loading a sample xTEDS. You can then use the xTEDS generator to edit the sample data for your own purposes. Select an XTEDS below to get started.       Power Users         BreadBoard_June2007.xml BreadBoard_Nov2006.xml CSSAssy.xml DigitalSS.xml RWheelSingle xml RedFoad_Nov2006.xml SAE_Thermometer xml       Does users may also benefit from starting with an example xTEDS and to choose whether your xTEDS is for a device.         . Use the add Interface link under <i>Device</i> (or Application) to identify the device or application.       Use the add Interface link under <i>Device</i> (or Application) to identify the device or application.         . Use the add Interface link under <i>Device</i> (or Application) to identify the device or application.       Use the add Interface link under <i>Device</i> (or Application) to identify the device or application.         . Whee HSingle xml RWheelSingle xml Robotub xml SAE_Thermometer xml       Too the device in the frame starting with example xTEDS         . Click the <i>Veriseber</i> link for an interface to expand the Messages section. You can then add one or more Commands, Netifications, or Requests.         . Startwith Sample xTEDS       Startwith Empty xTEDS         . Whethe disting xTEDS, make use you generate a new xTEDS specification, you will tee an error message. To load the xTEDS any expression the device and rety.         . Whethe disting xTEDSS.       Betwee	g Started 📄 Google Bookmark 🔂 Latest Headlines 📄 Pizza Ontology 📄 News 📄 A - Mongo 📄 Create an a	secount or	
STEDS Generator - Getting Started         Beginners       Power Users         It is recommended that those new to XTEDS begin by loading a sample XTEDS. You can then use the xTEDS generator to edit the sample data for your own purposes. Select an XTEDS below to get started.       Power Users         BreadBoard_Nov/2005/xml       Get and the sample Atternet of the sample data for your own purposes. Select an XTEDS below to get started.       Power Users         BreadBoard_Nov/2005/xml       BreadBoard_Nov/2005/xml       Case the dit link under <b>ATEDS Identity</b> to identify your XTEDS and to choose whether your XTEDS is for a device.         CSSAes/xyml       BreadBoard_Nov/2005/xml       But the but on below perform the following:         DigitalSS.xml       Case the did link drade <b>Device</b> (or Application) to identify the device or application.         Mag Torque Rodurnl       WitherelAssyxml         RW/meelXisgyxml       Case the did link for an interface to expand the Variables section. You can then add one or more variables that can be used in messages.         Start with Sample XTEDS       Start with Empty XTEDS         Start with Sample XTEDS       Start with Empty XTEDS         Start with Sample XTEDS       Start with Empty XTEDS         Start with Exsting XTEDS       Start with Exsting XTEDS         Start with Exsting XTEDS       Start with Empty XTEDS         Start with Exsting XTEDS       Start with Empty XTEDS         Start wit	Design Corporation 🛛 🔄 Getting Started - xTEDS Generator 🖾		
Area       Degrames         It is recommended that those new to XTEDS begin by loading a sample XTEDS. You can then are stTEDS generator to edit the sample data for your own purposes. Selet an XTEDS below to an to start form scarch, use this option.       Area         It is recommended that those new to XTEDS begin by loading a sample XTEDS. You can the area       Core users may also benefit from starting with an example XTEDS on the left, however if you just to start to start form scarch, use this option.         It is recommended that those new to XTEDS begin by loading a sample XTEDS is dealt by the device of application.       Area         It is recommended that those new to XTEDS and to choose whether your XTEDS is for a device.       Use the edit link under <i>XTEDS identity</i> to identify your XTEDS and to choose whether your XTEDS is for a device.         It is the add interface link under <i>XTEDS identity</i> to identify your XTEDS and to choose whether your XTEDS is for a device.       Use the edit link under <i>XTEDS identity</i> to identify your XTEDS and to choose whether your XTEDS is for a device.         It is the add interface link under <i>XTEDS identity</i> to add at least one interface to expand the Vatables section. You can then add one or more variables that can be used in messages.       Click the <i>Varrader</i> link for an interface to expand the Vatables section. You can then add one or more Commands, Notifications, or Requests.         Is attrike Stards <i>XTEDS</i> from your computer so you can view it and/or modify it. Use the <i>Brewse</i> button to select the file on your computer. After selecting a file, use the <i>Start with</i> the your computer.         Start with Existing <i>XTEDS</i> is more your computer so you can view	xTEDS G	ienerator	
<ul> <li>Is recommended that those new to XTEDS begin by loading a sample XTEDS. You can then use strEDS generator to edit the sample data for your own purposes. Select an XTEDS below to set the same stret from strating, use this option.</li> <li>Arter disking the button below perform the following:</li> <li>Use the edit link under <i>XTEDS Identity</i> to identify your XTEDS and to choose whether your XTEDS is for a device.</li> <li>Use the edit link under <i>Interface</i> (or Application) to identify the device or application.</li> <li>Use the edit link under <i>Interface</i> to expand the Variables section. You can then add one or more variables that can be used in messages.</li> <li>Use the edit link under <i>Interface</i> to expand the Variables section. You can then add one or more variables that can be used in messages.</li> <li>Click the <i>Variables</i> link for an interface to expand the Variables section. You can then add one or more variables that can be used in messages.</li> <li>Click the <i>Messages</i> link for an interface to expand the Variables section. You can then add one or more variables that can be used in messages.</li> <li>Click the <i>Messages</i> link for an interface to expand the Variables section. You can then add one or more variables that can be used in messages.</li> <li>Click the <i>Messages</i> link for an interface to expand the Variables section. You can then add one or more Commands, Notifications, or Requests.</li> <li>Click the <i>Messages</i> link for an interface to expand the Variables section. You can then add one or more Commands.</li> <li>Stertwith EmptyXTEDS</li> <li>Messages button to bead an existing a file ose not comform to the XTEDS specification, you will see and mer serves subton to spelet the file on your computer. After selecting a file, use the Stert with try vou computer.</li> <li>Stertwith Existing XTEDS</li> <li>Wheelassing XTEDS</li> <li>Messages link Existing XTEDS and we are you generate a new XTEDS when you are finished and save it to your computer. After selecting a file, use the Stert with</li></ul>	xTEDS Generator	Getting Started	
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Breadboard_Unv2006xml       xTEDS is for a device.         Breadboard_Nov2006.xml       .         CSSAssyxml       .         DigitalSS.xml       .         GPS_Fullxml       .         MagTorqueRodxml       .         WheelAssyxml       .         RWheelAssyxml       .         Start with Sample xTEDS       .         Start with Sample xTEDS       .         Returning Users       .         Use this option to load an existing xTEDS from your computer so you can view it and/or modify it. Use the Browse button to select the file on your computer. After selecting a file, use the Start with Existing xTEDS make sure you generate a new XTEDS when you are finished and save it to your computer.         Start with Existing xTEDS       .         Browse       .         Perform Validation       .         General Tips       .	started.	After clicking the button below perform the following:	
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GPS_Full xml   MagTorqueRod xml   RWheelAssy xml   RWheelAssy xml   RWheelAssy xml   RWheelAssy xml   Start with Sample xTEDS   Start with Sample xTEDS from your computer so you can view it and/or modify it. Use the Browse button to select the file on your computer. After selecting a file, use the Start with Existing xTEDS from your comfort to the xTEDS specification, you will see an error message. To load the xTEDS anyway, uncheck the Perform Validation checkbox and retry. If you choose to edit data in the xTEDS, make sure you generate a new XTEDS when you are finished and save it to your computer.    Start with Existing xTEDS   Browse   If you choose to edit data in the xTEDS, make sure you generate a new XTEDS when you are finished and save it to your computer.		2. Use the edit link under <b>Device</b> (or Application) to identify the device or application.	
MagTorqueRod.xml   RWheelAssy.xml   RWheelAssy.xml   RWheelAssy.xml   RWheelAssy.xml   RWheelAssy.xml   RoboHub.xml   SAE_Thermometer.xml		3. Use the add interface link under Interfaces to add at least one interface to your xTEDS.	
RWheelSingle xml   RoboHub xml   SAE_Thermometer.xml	MagTorqueRod.xml		
Start with Sample xTEDS       Start with Empty xTEDS         Returning Users       Use this option to load an existing xTEDS from your computer so you can view it and/or modify it. Use the Browse button to select the file on your computer. After selecting a file, use the Start with Existing xTEDS button to begin. If the file does not conform to the XTEDS specification, you will see an error message. To load the xTEDS anyway, uncheck the Perform Validation checkbox and retry. If you choose to edit data in the xTEDS, make sure you generate a new xTEDS when you are finished and save it to your computer.         Start with Existing xTEDS       Browse         Perform Validation       Browse         General Tips       Browse	RWheelSingle.xml RoboHub.xml		
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•	Perform Validation		
	General Tips		
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#### Standards- "Help-Desk" Approach

- Let's establish a foundation within a non-profit to serve as a go-to
- A central place for
  - Standard drafts
  - Education / training
  - Workshop coordination
  - Community indexes
  - Databases for software, component libraries, design aids
- Support needed for
  - Secretariat administrative roles for brokering the standards to a publishable form
  - Supplemental IT support to create the public and member only sections of the website and support the databases necessary
  - Manpower to create the documents, evolve to a useable form (ex. In PnP, anyone smart enough to create the document is dedicated to creating the technology – sound familiar?)

### Conclusions

- Key principles of SPA as a disruptive technology
  - Smart interfaces, self-description, casual arrangement of network element, complexity hiding and encapsulation, robust software infrastructure (SDM)
  - Push-button toolflow (embodied in the Mission Sattelite Design Toolkit)
- Dramatic benefits: faster, more flexible, more robust, less expensive systems
- SPA-U/SPA-S infrastructure has advanced enough for serious prototype development
- Critical point in evolution how do we cross the chasm (technological valley of death)?
- Promotion through standards, small business community to push technology to a critical "tipping point"

### Acknowledgements

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