



**Software Defined Radio
Standard Architecture and its
Application to NASA Space Missions**

OMG Space DTF Information Day

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Abstract

A software defined radio (SDR) architecture used in space-based platforms proposes to standardize certain aspects of radio development such as interface definitions, functional control and execution, and application software and firmware development. NASA has chartered a team to develop an open software defined radio hardware and software architecture to support NASA missions and determine the viability of an Agency-wide Standard. A draft concept of the proposed standard has been released and discussed among organizations in the SDR community. Appropriate leveraging of the JTRS SCA, OMG's SWRadio Architecture and other aspects are considered.

A standard radio architecture offers potential value by employing common waveform software instantiation, operation, testing and software maintenance. While software defined radios offer greater flexibility, they also poses challenges to the radio development for the space environment in terms of size, mass and power consumption and available technology. An SDR architecture for space must recognize and address the constraints of space flight hardware, and systems along with flight heritage and culture.

NASA is actively participating in the development of technology and standards related to software defined radios. As NASA considers a standard radio architecture for space communications, input and coordination from government agencies, the industry, academia, and standards bodies is key to a successful architecture. The unique aspects of space require thorough investigation of relevant terrestrial technologies properly adapted to space. The talk will describe NASA's current effort to investigate SDR applications to space missions and a brief overview of a candidate architecture under consideration for space based platforms.

FYI Only: not part of actual presentation



Overview

- Communications Technology at Glenn Research Center
- NASA's Mission Drivers and Applications
- NASA's SDR Reference Architecture
- Relationship among standard bodies – NASA, OMG, SDRF, IEEE, JTRS
- Concluding Remarks



Glenn Research Center Communications Technology Overview



Aerospace Communications Historical Perspective

- From the early 1970's to 1998 GRC's Space Comm program's primary responsibility was to open new frequency bands and provide enabling communications technology to the commercial SATCOM industry.
 - Provided the high power communications payload to the joint-Canadian CTS Satellite that opened the Ku-band for DBS and FSS services in the late 1970's.
 - Received an Emmy from the National Academy of Television Arts and Sciences
 - Developed and validated high-risk Ka-band technology via ACTS Satellite Program for the next generation satellite systems, 1990's
 - ACTS inducted into Space Technology Hall of Fame
- Pioneered satellite communications to aircraft
- Developed technologies to enhance Internet over satellite operation

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Aerospace Communications Today

- Develop next generation space communication systems and networking technologies for NASA Missions and to enhance NASA's Space Communications Infrastructure.
 - Software Radio/Digital Communications
 - Antennas (high gain deployable, steerable/directional arrays)
 - Power Amplifiers
 - System Architectures, Networking, and Analysis
- Develop communication and networking systems technologies to enhance the National Airspace System.

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Aerospace Communications Research & Technology

Capabilities

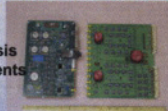
Facilities/Testbeds/Validation

Network & Architectures



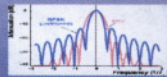
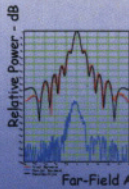
Space & Aero
System
Architectures
Systems Analysis
Tech Assessments

Digital Communications Software Defined Radios



High Speed modems and
specialized digital hardware
Space Network Interface Card

Systems Analysis Simulation and Modeling



Antennas, Optical and RF devices



GaAs MMIC Ka-Band
Phased Array



Ferroelectric
Scanning
Reflectarray
Antenna



Aero Phased Array



Power Amplifiers & Electronic Devices



Cassini TWTA

Laboratories



Mobile Test Platforms



Antenna
Range



ACTS Satellite

Flight Experiments



- Learjet
- DC-8
- 767



Mission Drivers and Requirements for SDR Recent Reconfigurable SDR Missions



Future Space Communications Architecture A Network of Networks

Mission Types

Crewed Vehicles

- Transport Vehicles
- Space Stations/Outposts
- Crew Activity (i.e. EVA)

Robotic Spacecraft

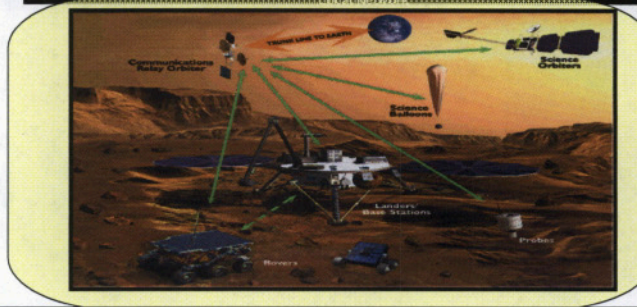
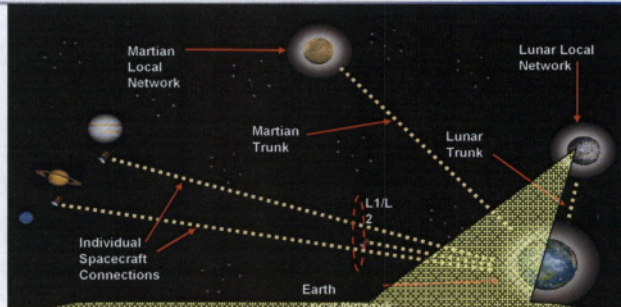
- Science Satellites
- Orbiting Relay Satellites

Surface Radios

- Rovers
- Science Elements
- EVA

Other...

- Launch Vehicles
- Sub-Orbital Vehicles
- Ground Stations



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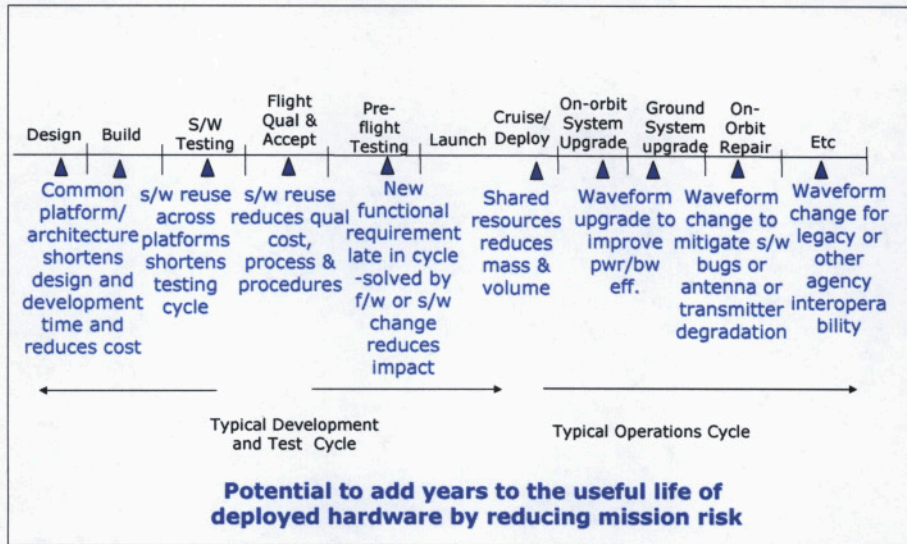
Drivers for NASA Space SDR

- Mission Services
 - Space Network, Ground Network, Deep Space Network,
- User Platforms
 - International Space Station, Shuttle, Earth Science, Space Science, Space Exploration, Crew Exploration Vehicle - Orion
- Mission Operations
 - Telemetry, command, control, science, tracking, scheduling, ranging (inter-satellite), networking
- Waveform Aspects
 - Frequency, data rate, access, modulation, networking
- On-orbit Operations
 - Reliability (hw/sw, single point failures)
 - Contingencies
 - Interoperability (among/between NASA and OGA assets)
 - New opportunities/updates
- Space Environment
 - Space Effects (e.g. HW - SEU/TID, SW - EDAC)
 - Capability - technology lag compared to terrestrial equivalents
- Future Missions Requirements
 - Development time
 - Changes (requirements creep)
 - Insert technology advancements
 - Culture

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Timeline of SDR Benefits Before and After Launch



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Open Architecture SDR Sample Benefits/Limitations


Benefits

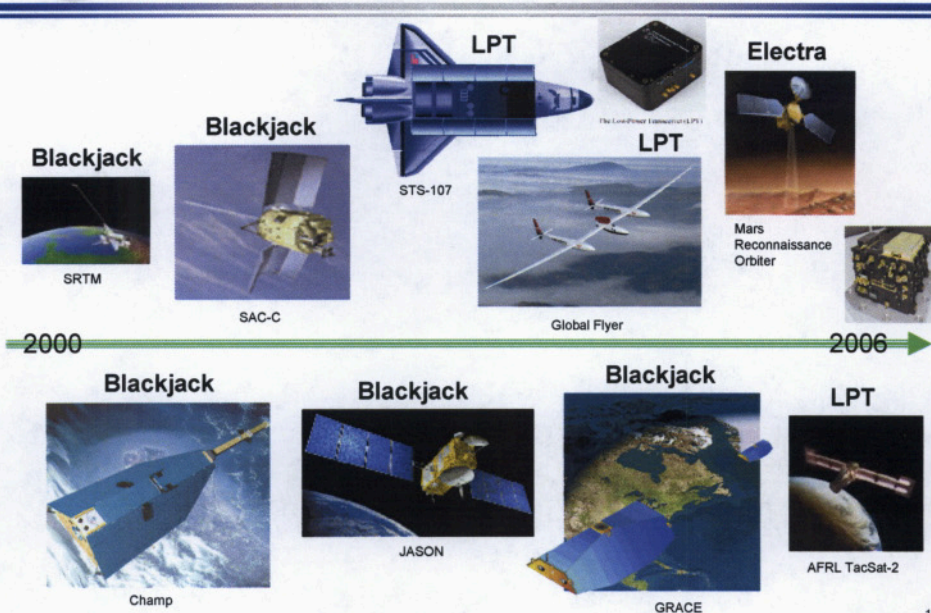
- **Flexible**
 - Hardware and software standard interfaces enable interoperability
 - Open interface and hardware/software separation allows technology insertion for planned obsolescence
 - Re-programmability allows pre- and post-launch changes
 - Enables backwards compatibility with legacy systems
- **Cost**
 - Simplify new mission adoption by reuse of standard hw and sw components
 - Multiple applications on a single hardware system
- **Resources**
 - Reduced radio count by combining functions to single/fewer processors or platforms

Limitations

- **Reliability**
 - Space qualification and lack of direct control over third party developed software
 - Difficult to verify and validate software compared to traditional hardware process
 - Need to verify on-orbit software reconfigurations
- **Cost**
 - Potentially high cost to create and sustain architecture if substantially different from SCA or commercial standard
 - Is common NASA, DoD, and commercial architecture needed to maximize market for space radios to reduce cost
- **Resources**
 - Potential for increased processing (i.e. power) requirements and larger form factors vs. predominately hardware based solutions (e.g., ASIC)
 - Additional processes to prevent memory corruption, resource contention, space effect upsets, and lockup conditions

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 **NASA Reconfigurable, Software Defined Radio Technology in Flight**



2000 → **2006**

Blackjack (SRTM), **Blackjack** (SAC-C), **LPT** (STS-107), **LPT** (The LowPower Transceiver (LPT)), **Electra** (Mars Reconnaissance Orbiter), **Global Flyer**, **Blackjack** (Champ), **Blackjack** (JASON), **Blackjack** (GRACE), **LPT** (AFRL TacSat-2)

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 **Open Architecture for Space, Why now?**

Signal Processing Advancements

Software/Firmware

Emerging Open Architectures

New Radio Technology

Commonality/Technology Insertion

Adaptable Operations, Fault Recovery, Flexibility

- Technology advancements in signal processing hardware make it possible for space based reconfigurable platforms
- Technology allows use of more software intensive systems for communication and navigation functions.
- Standard architectures for SDR emerging
 - JTRS, OMG, SDR Forum, etc....
- SDR's being used in missions and technology demos (e.g. MRO, STS-107) without benefit of commonality or leverage from one development to another

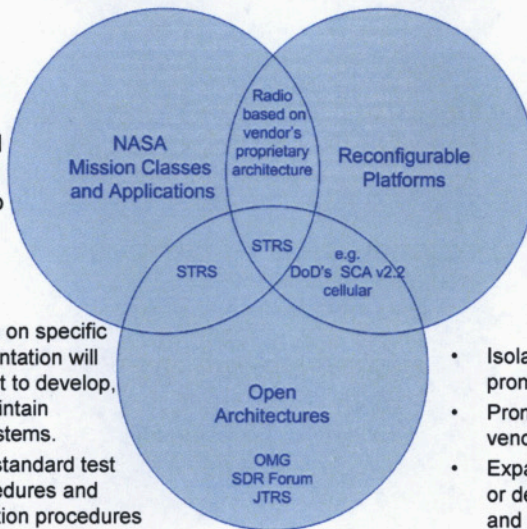
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Applying SDR and Standard Architectures to NASA

- Missions will apply reconfigurable radio technology and standard architectures to best meet requirements

- Less dependence on specific vendor's implementation will reduce NASA cost to develop, augment, and maintain reconfigurable systems.
- Provides path to standard test qualification procedures and validation/verification procedures as software use increases



- Vendors will pursue reconfigurable platforms going forward – conventional radios will be reconfigurable (e.g. SDR)

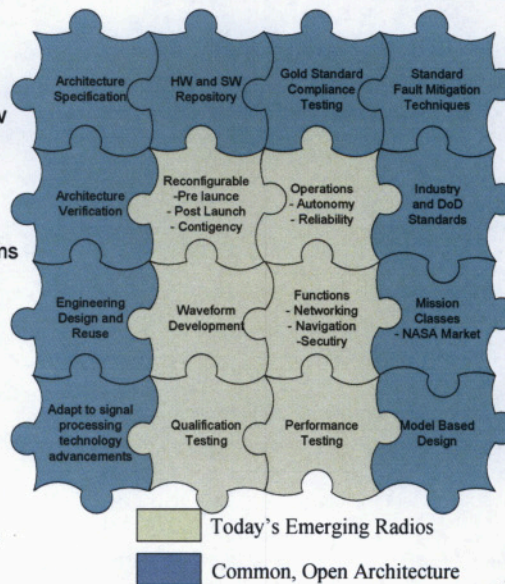
- Isolate SW from HW to promotes reuse
- Promotes/enables multi-vendor participation
- Expandability – provide or define more interfaces and capability as requirements and technology mature.

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Aspects of SDR and Architectures How the pieces fit...

- “SDR” means more than just “reconfigurable”
- Today's radio technology offers new development and operational paradigms
 - Upgradable
 - Flexible
 - Industry trends to SW based systems
- Architecture adds framework to reconfigurable (SDR) transceiver technology
 - Multi-vendor participation
 - Common Interfaces
 - Technology Insertion
 - Common Specification
 - Reuse
 - Software verification - Developing a qualification approach suitable for missions

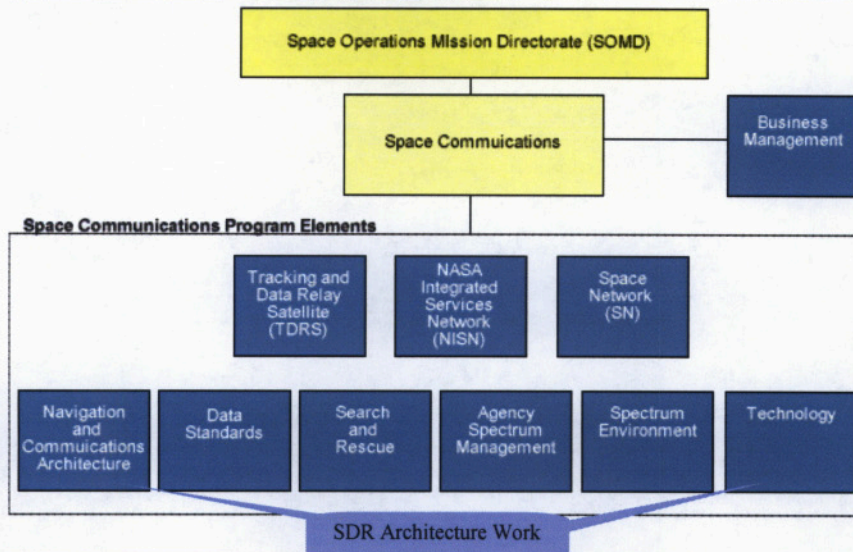


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Communication and Navigation within NASA

Space Communications Organization Chart



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SAT Approach to Development and Implementation of the STRS SDR Standard Architecture

Create a broad-based SDR development and verification infrastructure to enable a future Agency-wide SDR standard

1. Develop the STRS SDR Standard Architecture Specification
 - Maintain flexibility as appropriate, solicit feedback from government and industry
 - Release 1.0 released in May ~~2006~~ 2006 ←
2. Develop an SDR distributed HW and SW component library
 - Solicit component entries from all viable sources
 - Projects select and procure library components as needed
3. Develop Design Reference Implementations using standard-compliant library components
4. Develop tools and testbeds for SDR design and validation
5. Demonstrate STRS-compliant units in space

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SAT Key Recommendations to SCAWG

- **Recognize that SDRs will play a key role in future NASA missions**
 - SDR technology demonstrated in flight testing and operations
 - Blackjack, LPT, Electra
 - Today's space radios typically have significant functionality implemented in software
 - Standardized SDRs may provide cost savings over time and multiple projects
 - However, business case needs to be compelling
 - Commonality should reduce development risk and NRE costs
- **Adopt the STRS Standard as a reference HW and SW SDR Standard and the associated Design Reference Implementations as such**
 - Promote a broad environment of acceptance and evolution of the Standard
- **Phase in compliance to the STRS Standard over time**
 - Encourage, but do not require, compliance to early versions of the Standard
 - The STRS Standard will be flexible and will be allowed to evolve as appropriate
- **Support technologies required to improve SDR performance for space**
 - radiation mitigation, processor throughput, FPGAs, ADC rates, memory, etc.



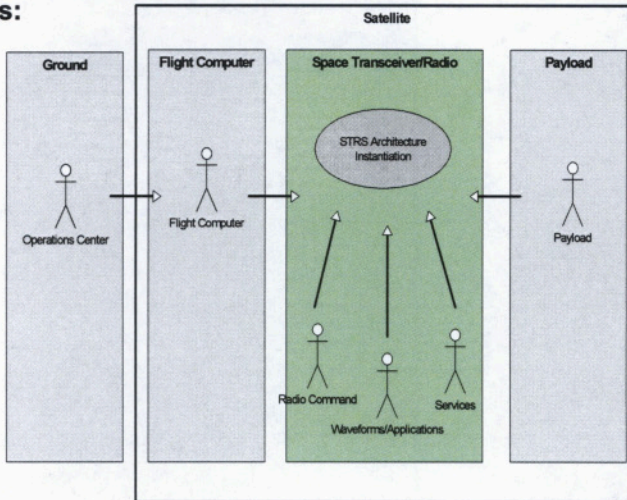
NASA's SDR Reference Architecture for Space



STRS SDR System Context

STRS Radio Elements:

- Waveforms
 - Communications
- Applications
 - Security
 - Health monitor
- Services
 - WF Upload
 - WF Instantiation
- Flight computer
 - Commands
 - Telemetry

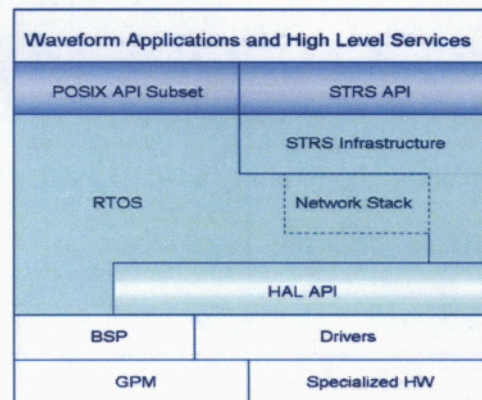


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STRS Layered Software Model

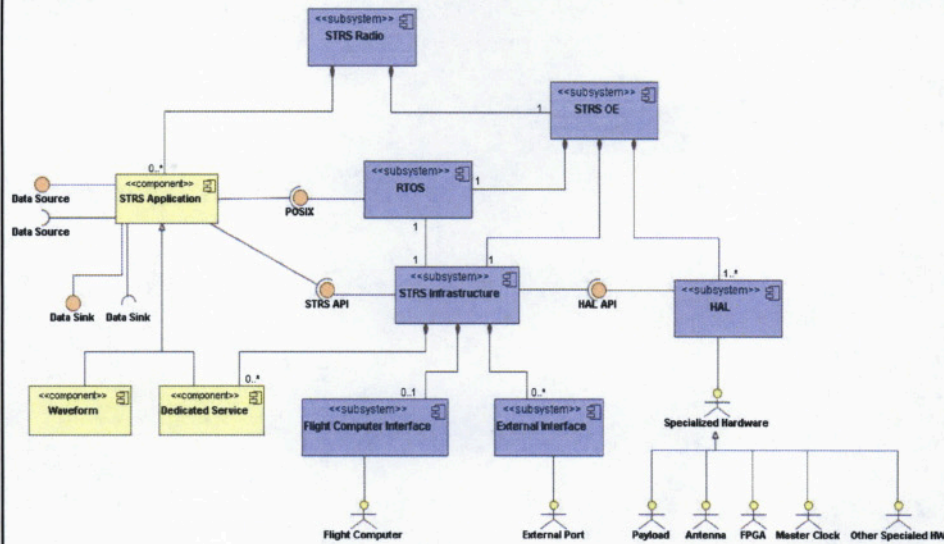
- **Waveform Applications**
 - Isolate from hardware
 - Uses POSIX APIs to access RTOS
 - Uses STRS APIs to access STRS infrastructure
 - Promote waveform portability/layering
- **High Level Services**
 - Control waveform
 - Monitor waveform (QoS)
- **STRS Infrastructure**
 - System management
 - Device control
 - Data transfer
 - Optimized for platform
- **RTOS**
 - Real-Time Operating System (COTS)
 - System implementing a subset of POSIX
 - Network Support
- **BSP (Board Support Package)**
 - Hardware Abstraction Layer (HAL)
 - Drivers
 - Hardware Interface (HID)
- **Hardware**
 - Hardware communications equipment (e.g. FPGA, DSP, A to D, and D to A)
 - HW Interface Definition – Facilitate HW tech insertion from multiple vendors (e.g. ICD)



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STRS Software Abstraction



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STRS Software Rule Set Sample

- The API layer shall consist of published STRS APIs and a defined subset of industry standard POSIX APIs
- The STRS infrastructure shall implement the STRS APIs and system management, device control, data transfer functions
- All STRS waveform applications shall use the STRS API suite to instantiate and control the waveform functionality
 - The STRS API provides the interfaces that allow applications to be instantiated and use platform services - these APIs also enable communication between waveform and application components
- Operating environment consists of STRS infrastructure, real time OS, board support packages, hardware abstraction layers
- STRS configuration files shall contain platform and waveform specific information to allow customization of installed waveforms.
 - The configuration file contains the parametric values for configurable components as well as filenames for loadable devices (FPGA, DSP, etc.)



Hardware Modules Functional Diagram (Draft)

RF Module

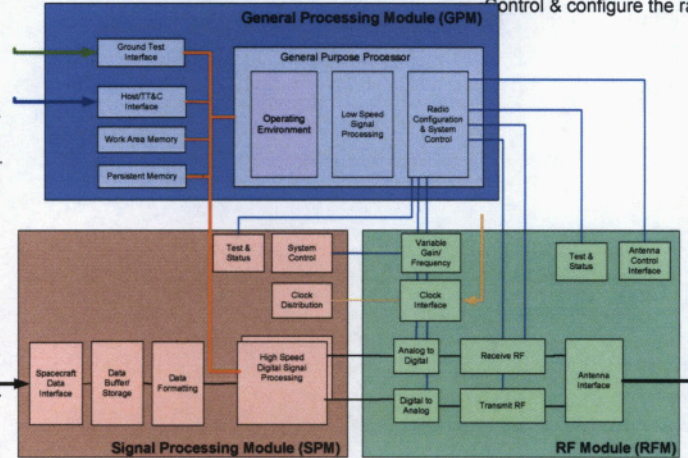
- Clock Interface
- Frequency Conversion
- RF components (switches, diplexer, filters, LNAs and power amplifiers)

Signal Processing Module

- Data Interface (e.g. high rate, direct IO)
- High speed DSP
- Data conversion (packetize)
- Components include ASIC's, FPGA's, DSP's, memory, and connection fabric/bus (e.g. flex-fabric)

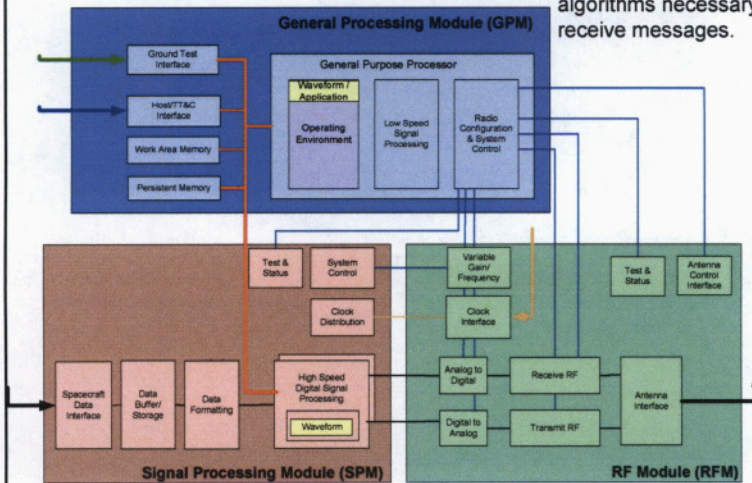
General Processing Module

- Spacecraft telemetry interface
- Test interface
- Components: GPP, memory (e.g. SRAM, SDRAM)
- Control & configure the radio.



Waveform Component Allocation to Hardware Modules

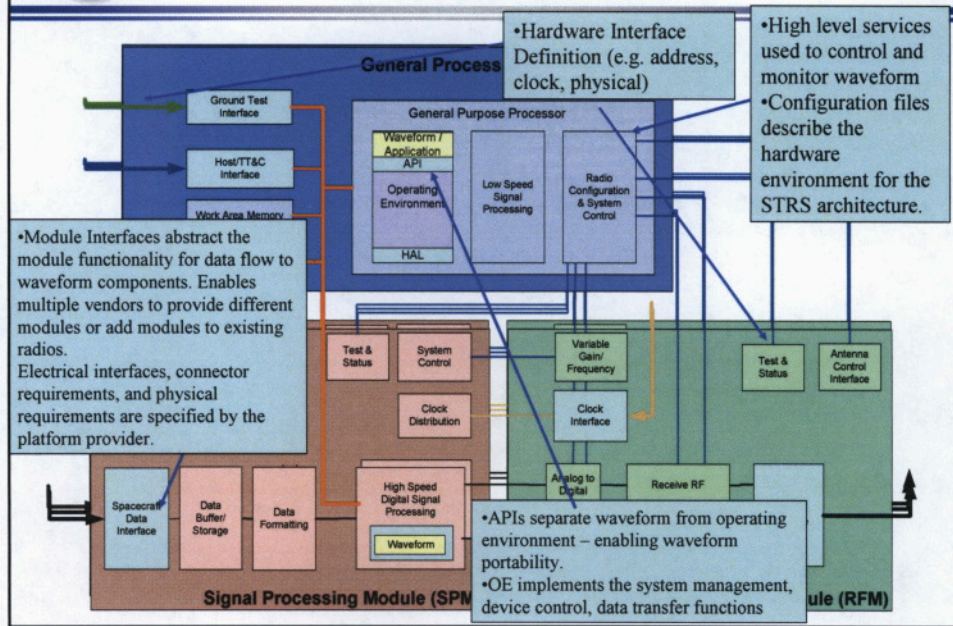
- Waveforms are comprised of software components with signal processing algorithms necessary to transmit and receive messages.



- Waveform components allocated to processing (GPP) and specialized hardware (SPM).



STRS Hardware Module & Interface Descriptions



STRS Interface Descriptions

Hardware

- Module definitions provided to organize common functions
- Module interfaces abstracts the module functionality for data flow to waveform components
 - Enable multiple vendors to provide different modules or add modules to existing radios.
 - Provide common test interface/procedures
- Hardware Interface Definition
 - The electrical interfaces, connector requirements, and physical requirements are specified by the platform provider.
 - HID shall be published for each module so 3rd party developers have the structure under which they can develop new modules

Software

- Layers help define interfaces between components
- Certain layers separate SW from SW and other SW from HW (i.e. abstract)
- APIs defined by the architecture separate waveform from operating environment for waveform portability and software reuse
- The STRS Infrastructure will use the HAL information to initialize the hardware drivers such that the control and data messages will be appropriately delivered to the module.
 - Method/function used, calling sequence, return values, an explanation of its functionality, any preconditions before using the method/function and the status after using the method/function
 - Hardware address and data interfaces, interrupt input and output, power connections, control and data lines necessary to operate in the STRS platform environment (firmware code portability)
 - Portable operating environment



SDR Standards Coordination

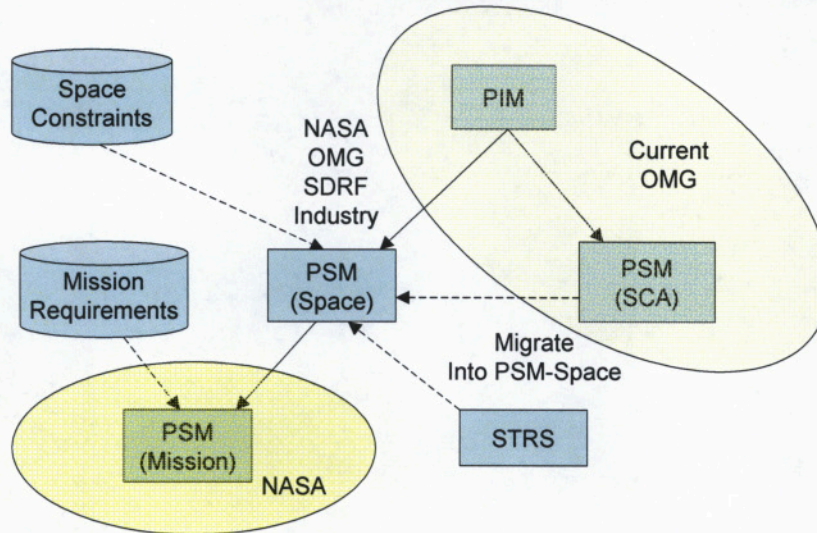


SDR Standards Coordination

- Organizations pursuing SDR Standards
 - Software Communications Architecture (SCA:JPEO/JTRS)
 - Specialized Hardware Processors Extension to the SCA (SHPE:JPO)
 - PIM/PSM For Software Radio Components (P2SRC:OMG)
 - P1900 (IEEE EMC Society)
 - Space Telecommunications Radio System (STRS:NASA)
 - Others...
- NASA participates in many of the SDR Standard activities in various ways
- NASA's STRS developed in 2004/2005 considered aspects of SCA and early versions of SWRADIO.
- NASA will strive to leverage commercial standards as they meet the requirements of space missions
- Continue to monitor SCA, OMG, and P1900 advancements
 - NASA investigating the application of current SWRADIO PIM/PSM for Software Radio Components in conjunction with SDR Forum, Space Applications Study Group



Government and Standard Bodies Coordination for Space SDR



SDR & STRS Architecture Conclusions

- Reconfigurable SDR will enable new mission concepts
 - Remote/autonomous operations
 - Future cognitive radios
- STRS Architecture provides commonality among reconfigurable SDR developed by NASA
 - Provides a coordinated method across the agency to apply SDR technology
 - Program/mission risk reduction
 - Allows technology infusion
 - Reduces vendor dependence
- STRS Architecture will evolve before becoming a required Standard
 - Waveform Control
 - Navigation, Security, Networking...
 - Business case for Standard Architecture pending...
 - Leverage best aspects of DoD's JTRS SCA and industry practice
- Exploration Vision will present opportunities to apply SDR

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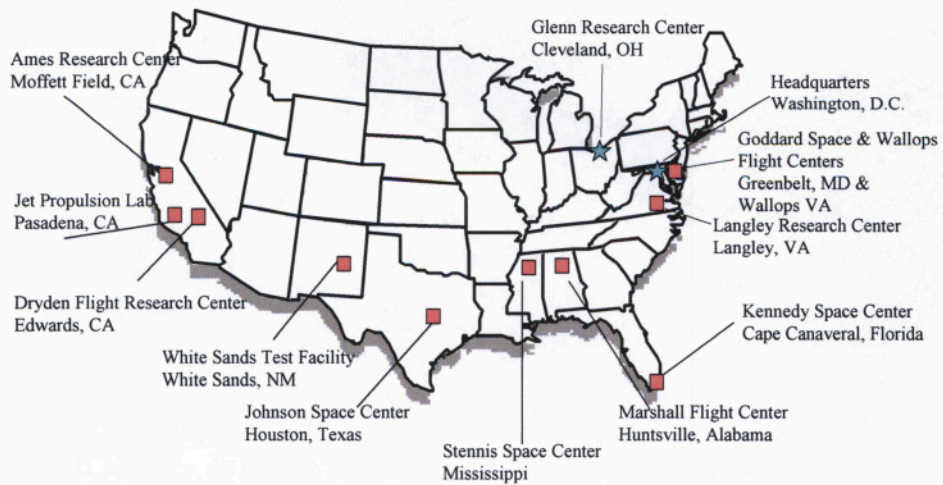


Backup

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NASA Center Locations



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