Lessons Learned Operating Software Defined Radios in Space

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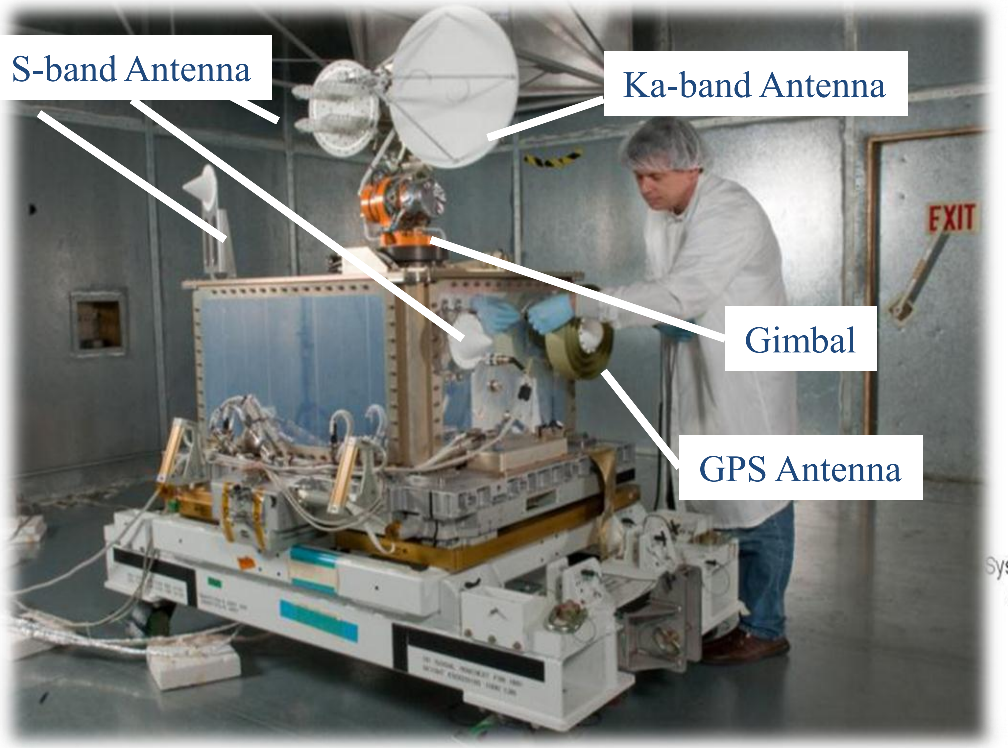
Wireless Innovation Forum Technical Conference
Schaumburg, Illinois
March 2014

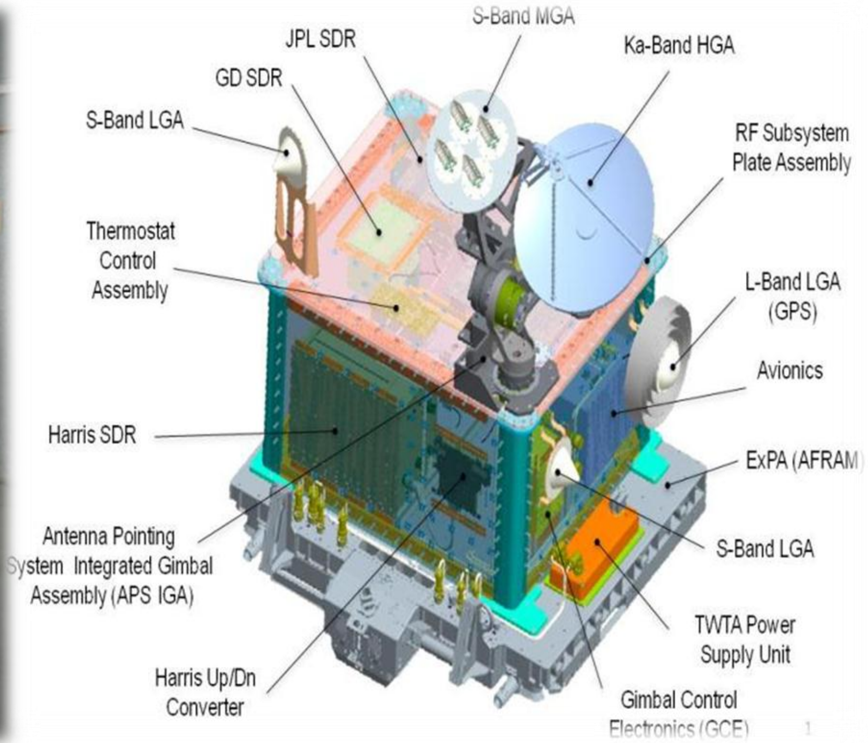
SCaN = Space Communication and Navigation

Many Aspects of SDRs for Space

- **Mission approach to telecomm - lowest risk, but meet science requirements - What worked last time?**
    - SDRs still a newer technology for space, although SDR flying at Mars since 2006 (MRO- Mars Reconnaissance Orbiter)
  - Driven by requirements e.g. do I need to reconfigure on-orbit?
- **Advantages –many "ilities" e.g. Flexibility, Reconfigurability**
  - More capable to run waveforms: modem, coding, network, apps
  - Handle new requirements or fix issues during development/ on-orbit
  - New Conops – adjust operations depending on mission findings
- **Challenges – Complexity, Resources**
  - Operations complexity
  - New software development
    - Dependence on Platform Developer (role for open architecture)
    - Development Tools/Expertise
    - Verifications of new software/VHDL for Flight
  - Hardware for space typically lags terrestrial parts

SCaN Testbed – Software Defined Radio-based Communication System





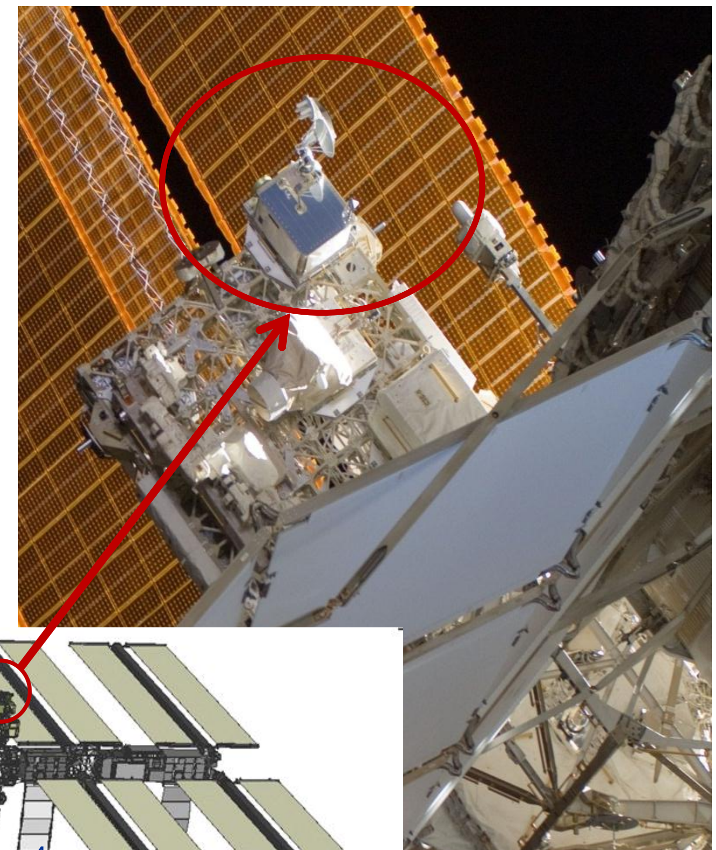
- SDRs - Two S-band SDRs (One with GPS), One Ka-band SDR
- Open standard for space SDRs: Space Telecommunications Radio System (STRS) STRS; NASA-STD-4009
- RF - Ka-band TWTA, S-band switch network
- Antennas - Two low gain S-band antennas, One - L-band GPS antenna, Medium gain S-band and Ka-band antenna on antenna pointing subsystem.
- Antenna pointing system - Two gimbals, Control electronics
- Flight Computer/Avionics

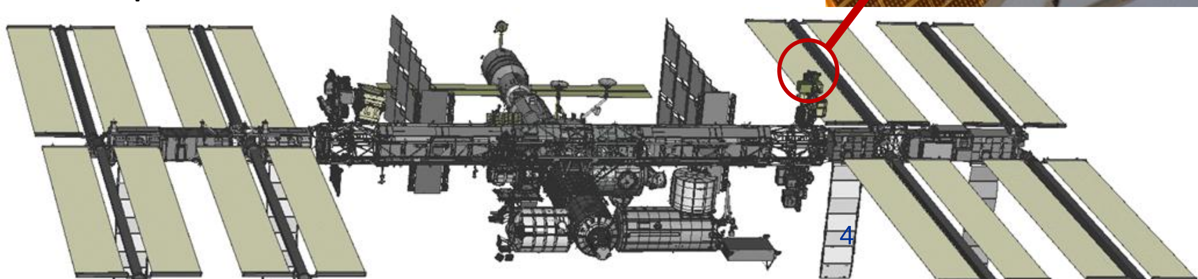
SCAN Testbed Mission Objectives

- **Mature Software Defined Radio (SDR) technologies and infrastructure for future SCaN architecture and NASA Missions**
  - Ready for space use/verification/reconfiguration/operations/new software aspects
  - Advance the understanding of SDR Standard, waveform repository, design references, tools, etc for NASA missions

- **Conduct Experiment's Program**
  - Portfolio of experiments across different technologies; communication, navigation, and networking
  - Build/educate a group of waveform developers and assemble repository of waveforms

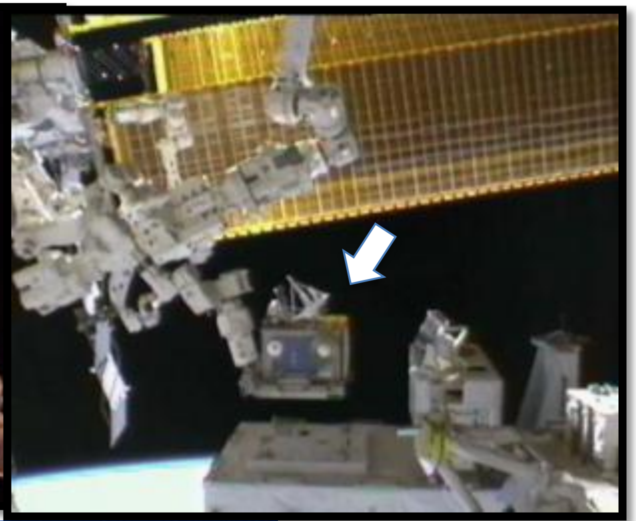
- **Validate Future Mission Capabilities**
  - Representative capabilities; S-band, Ka-band, GPS





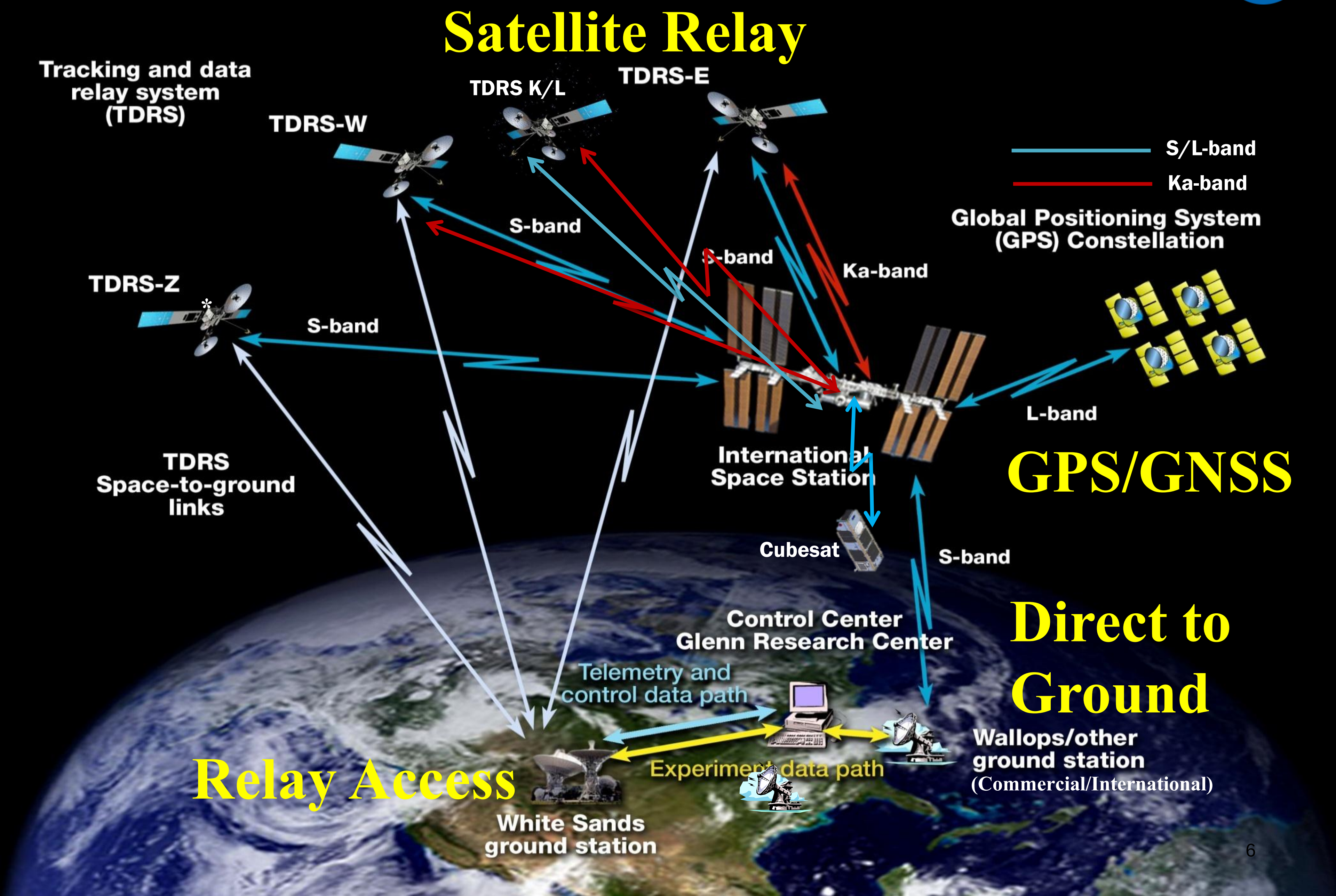
Pictures of Installation and ISS Location

Launched: July 20, 2012



SCaN Testbed on ISS: August, 28, 2013

SCAN Testbed System Architecture



LESSONS LEARNED

SDR Lesson Learned - Characterize SDR platform along with applications

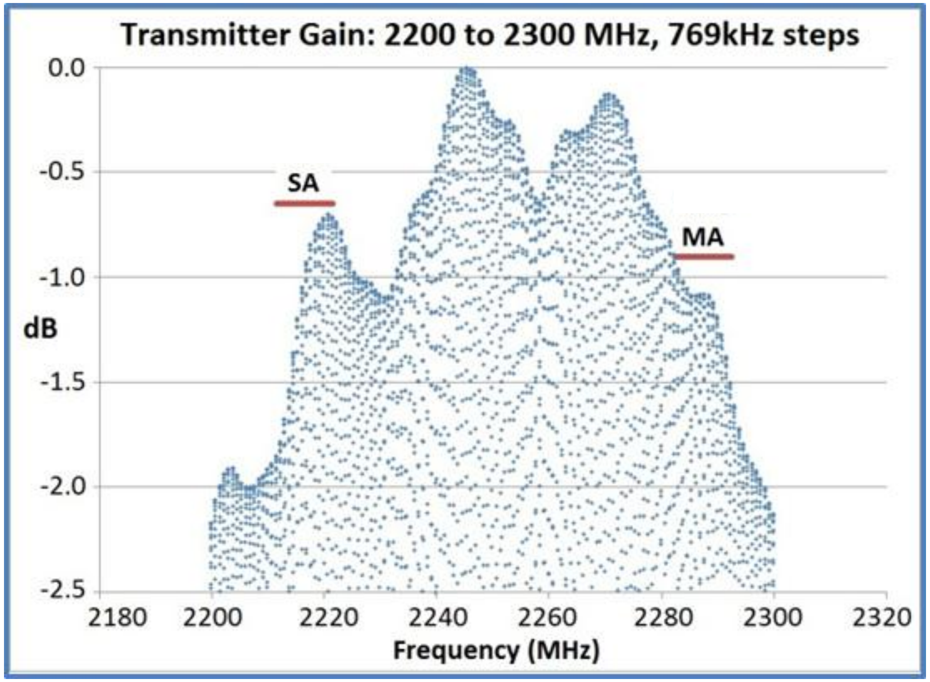
- Platform hardware much more capable than initial waveforms

- Require test waveforms from platform developer
  - Store ADC samples for post processing
  - Transmit arbitrary signals, stored file
  - Radio services
    - Receiver gain, rx/tx pwr level
    - Frequency tuning

- Requirements must reflect platform capability (not just initial waveforms) for verifications

Tx Frequency of platform

- NASA 6 MHz frequency allocation SA-Single Access, MA- Multiple Access
- SDR tunable across 100 MHz!



SDR Lessons Learned – Provide Path to Update Commanding and Telemetry

- **Provide flexible method to add commands and telemetry**
  - GD - Fixed bit positions in 1553 represent telemetry fields (most efficient)
  - Harris –Name value pairs; defined by property name in XML file
  - JPL –Heartbeat plus text over 1553, variable size and rate, free format (flexible, least efficient)

- **Most flexible = more complex**
  - Serial interface provides most information, but requires most returned amount of data
  - Not captured in 1 sec telemetry

Note: No specific NASA requirements for platform commanding due to schedule…used what was ready to go

Byte Number	Bit Width	Description
0	1	Sync (Receive BW Energy) Detect (1 = detected, 0 = not detected)
	1	Carrier Lock (1 = locked, 0 = not locked
	1	Main Lobe Detect (autocorr. of short PN) (1 = detected, 0 = not detected)
	1	PN Lock (1 = locked, 0 = not locked)
	1	Cmd Detector Lock (Bit Synch Achieved) (1 = locked, 0 = not locked)
	1	PN Long Code Detect (1 = detected, 0 = not detected)
	1	Viterbi Decoder Lock (1 = locked, 0 = not locked)
	1	Forward FEC (0 = disabled, 1 = enabled)
	1	Return FEC (0 = disabled, 1 = enabled)
	1	Coherency Status (0 = noncoherent, 1 = coherent)
	1	Internal/External 1PPS Enable (0 = internal, 1 = external)

```
<?xml version="1.0" ?>
<HarrisWaveFormPropertySettings>
  <Property name="STRS_APP_STATE" value="" />
  <Property name="APQM_DB" value="" />
  <Property name="RX_CENTER_FREQ" value="" />
  <Property name="RX_ATTEN_VAL" value="" />
  <Property name="USE_XML_DEFAULTS" value="" />
  <Property name="WF_GPP_INFO" value="" />
</HarrisWaveFormPropertySettings>
```

```
Terminal 6
Terminal   Edit   Settings
1043500134: 749466532 /STRS_telemetry_q: gps: JPLGGT Mode=B1
1043501497: 979950532 /STRS_error_q: gps: Disconnect Error 1
1043511403: 819682532 /STRS_telemetry_q: gps: JPLGGT Started
(STRS_APP_RUNNING State)
1043511404: 052908532 /STRS_warning_q: gps: WF_TimedTasks
():Despreader False Lock Detected, reaquiring
1043511404: 129762532 /STRS_telemetry_q: gps: WF_TimedTasks():New
Thresholds I:+1.4648E-03
1043511404: 149722532 /STRS_telemetry_q: gps: Monitor_Task: cl AGC
Scale changed to 1
```

SDR Lesson Learned - SDR Flexibility Leads to Complexity

- **Traditional radios - fixed set of functions, fixed command/telemetry, routine procedures, routine operations**

SDR

- **SDR wide skill set – RF, FPGA, GPP, software, standards**
- **SCaN TestBed uses the SDRs in different ways from day-to-day and each radio is different - STB CONOPs is different and more complex than most**

Operations

  - Command sets tend to grow with new waveforms
  - Scripts help automate sequence of commands, but require additional verification
- **Requires additional training and knowledge in operations**

System

- **For STB, troubleshooting system during a relay pass needs: operations knowledgeable of SDR, communication systems, relay satellite network (TDRS, WSC), or ground station, ground network, baseband processing**

SDR Operations Planning Interfaces

- **Requires coordination of a significant number of authorities**

Pre-planning

- Payload Activity Requirements Coordinator (PARC) at MSFC
- Payload Planning Manager (PPM) at MSFC
- Timeline Change Officer (TCO) at MSFC
- Flight Dynamics Facility (FDF) at Goddard Space Flight Center (GSFC)
- Network Integration Manager (NIM) at GSFC
- Mission Operations Directorate (MOD) /Operations/Pointing Coordinator at JSC
- MOD/Flight Design and Dynamics / Trajectory Operations Officer (TOPO) at JSC
- MOD/Expedition Vehicle Division/Attitude Determination and Control Officer (ADCO) at JSC

Real Time

- Operations Controller (OC) at MSFC
- Payload Operations Director (POD) at MSFC
- Payload Rack Officer (PRO) at MSFC
- Network Operation Manager (NOM) at GSFC
- Space Network (SN) or Near Earth Network (NEN) at White Sands, Wallops, etc.

SDR Operations Planning Activities & Timeline

Operations

- **Overall process is complex and requires much prior planning**
  - (T-5m) – Update payload flight rules (license) as required [PARC,PPM,OC]
  - (T-3m) – Translate experiment requirements to operational scheme
  - (T-3m) – Update payload RF codes for new experiment [SN, NIM]
  - (T-1m) – Submit on-orbit operations summary [PPM]
  - (T-3w) – Experimenter submits specific operations request to STB ops team
  - (T-2w) – Complete dry run of experiment on ground integration unit
    - Model ISS ephemeris for scheduling [GSFC Flight Dynamics Facility]
    - Model ISS attitude for scheduling [JSC ADCO – Attitude Determ / Control Officer]

ISS

  - (T-18d) – Submit weekly look-ahead plan update for ISS power [PPM]
  - (T-17d) – Submit TDRS/NEN comm service request (TSR) [SN]
  - (T-7d) – Receive TDRS schedule of accepted events [SN]

TDRSS

  - (T-7d) – Reserve TDRS unused time as needed to meet schedule req'ts [SN]
  - (T-0d) – Regenerate/upload STB antenna pointing track files
  - (T-0d) – Operate event, provide briefing to ISS and track orbit changes that could influence flight rules (power spectral density) [POD,PRO,OC,SN]
  - (T+0d) – Report on daily science accomplishments, anomalies, etc. [POD, etc]

SDR Lesson Learned – Software

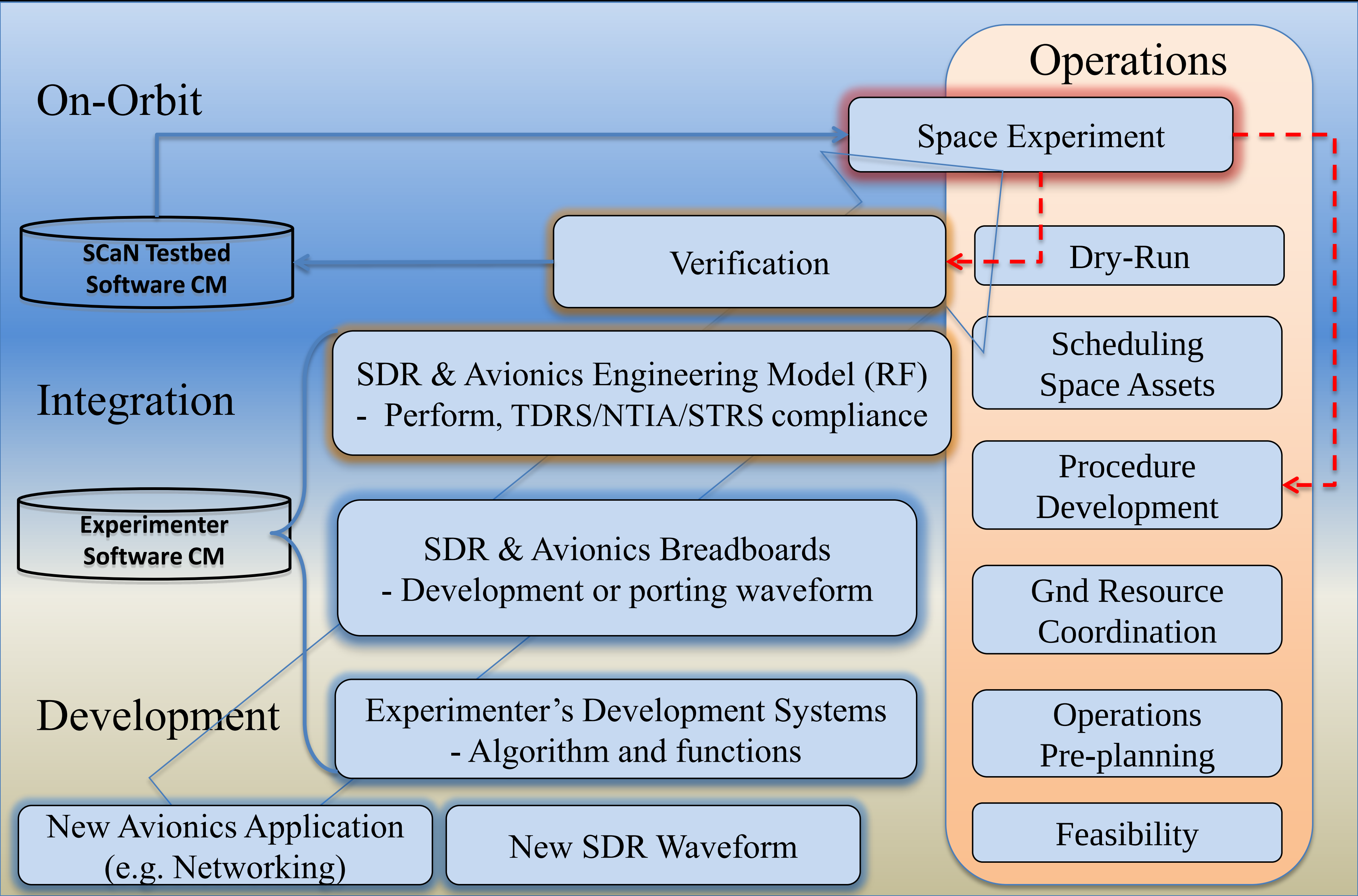
Platform developer provided software

- **Test waveforms serve as template for future waveform applications**
- **Deliver code that exercises platform resources & interfaces available to users (even if not in initial waveform)**
- **Ensure that test/delivered waveforms were developed using software wrapper to access platform resources and according to documentation**

New software, 3rd party delivered applications

- **Develop new waveform using only the available documentation to assess the documentation quality for future efforts**
  - Don’t rely on PDR/CDR material or other material…
- **Incentive for platform developers to aid waveform developers**
  - A successful product is a product people know, understand, and use
- **Continued role for platform developer – servicing/consulting (driven by platform complexity)**

New Experiment; Development and Operations Flows



SCaN Testbed & STRS – Upcoming Solicitations

SDR TECHNOLOGY REQUEST FOR INFORMATION (RFI)

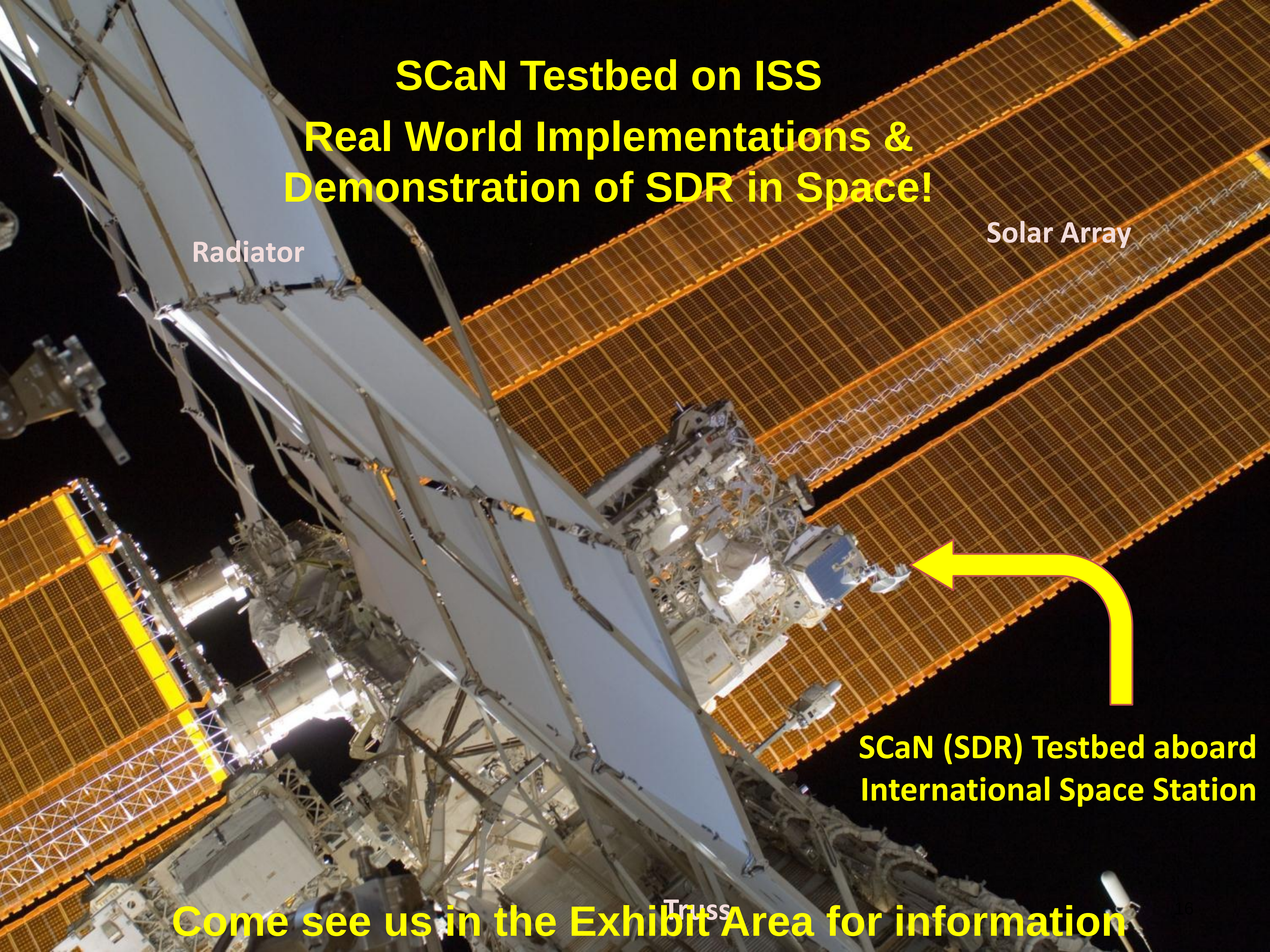
- Investigate the state of the art of near-term and long term, space applicable SDR technology and concepts - what follows "SDR"?, what's the next Testbed?
- Understand the barriers to establishing a developer community to create or reuse applications for NASA communication systems.
- Recommended updates to the STRS architecture NASA-STD-4009.

SCAN TESTBED EXPERIMENT OPPORTUNITIES

- Cognitive concepts for system efficiency (throughput, power, autonomy, spectrum)
- Funded call for University experiments to be announced soon (Coop Agreement)
- Unfunded/unsolicited proposals always welcome (Space Act Agreements)

FOR MORE INFORMATION:

Web site: http://spaceflightsystems.grc.nasa.gov/SOPO/SCO/SCaNTestbed/ or fbo.gov


SCaN Testbed on ISS
Real World Implementations &
Demonstration of SDR in Space!
Radiator
Solar Array
SCaN (SDR) Testbed aboard
International Space Station
Truss
Come see us in the Exhibit Area for information

SCaN Testbed Point of Contacts

- Project Website
  - http://spaceflightsystems.grc.nasa.gov/SOPO/SCO/SCaNTestbed

- Technical Contacts
  - Principal Investigator
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- Programmatic Contact
  - Project Manager
    - Mr. Dave Irimies
    - david.p.irimies@nasa.gov
    - 216-433-5979

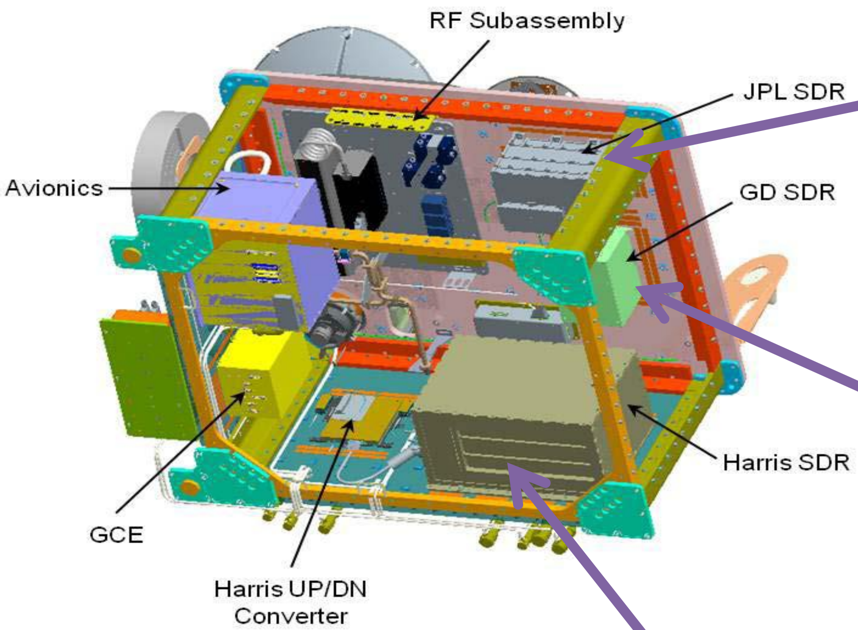
STRS and SCaN Testbed References

- Space Telecommunication Radio System Rel 1.02.1
  - NASA/TM—2010-216809/REV1
  - http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110002806_2011001718.pdf

- SDR/Winn Forum: Comments on NASA Space Telecommunications Radio System (STRS)
  - http://groups.winnforum.org/Recommendations
  - SDRF-07-R-0013-V1.0.0

- SCaN Testbed Overview, Documents, Links
  - http://spaceflightsystems.grc.nasa.gov/SOPO/SCO/SCaNTestbed/Candidate/

Software Defined Radios are the “Instruments” of the SCaN Testbed



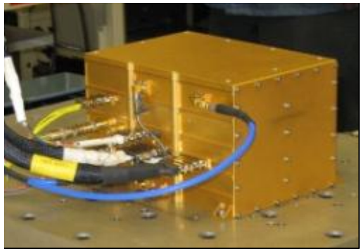
JPL/L-3 CE

- S-band SDR
  - 6 MHz wide channe
- L-band receive (GPS)
- Virtex II, 66 MHz Sparc Processor, RTEMs
- 10 Mbps Class
- STRS Compliant

Harris

- Ka-band SDR
  - 225 MHz wide channel
- Virtex IV, 1000 MIPS PowerPC Proc, DSP (1 GFLOP), VxWorks
- >100 Mbps Class
- STRS Compliant

General Dynamics



- S-band SDR
  - 6 MHz wide channel
- Virtex II, ColdFire Processor (60 MIPS), VxWorks, CRAM (Chalcogenide RAM) Memory
- 10 Mbps Class
- STRS Compliant