Unique Challenges Testing SDRs for Space

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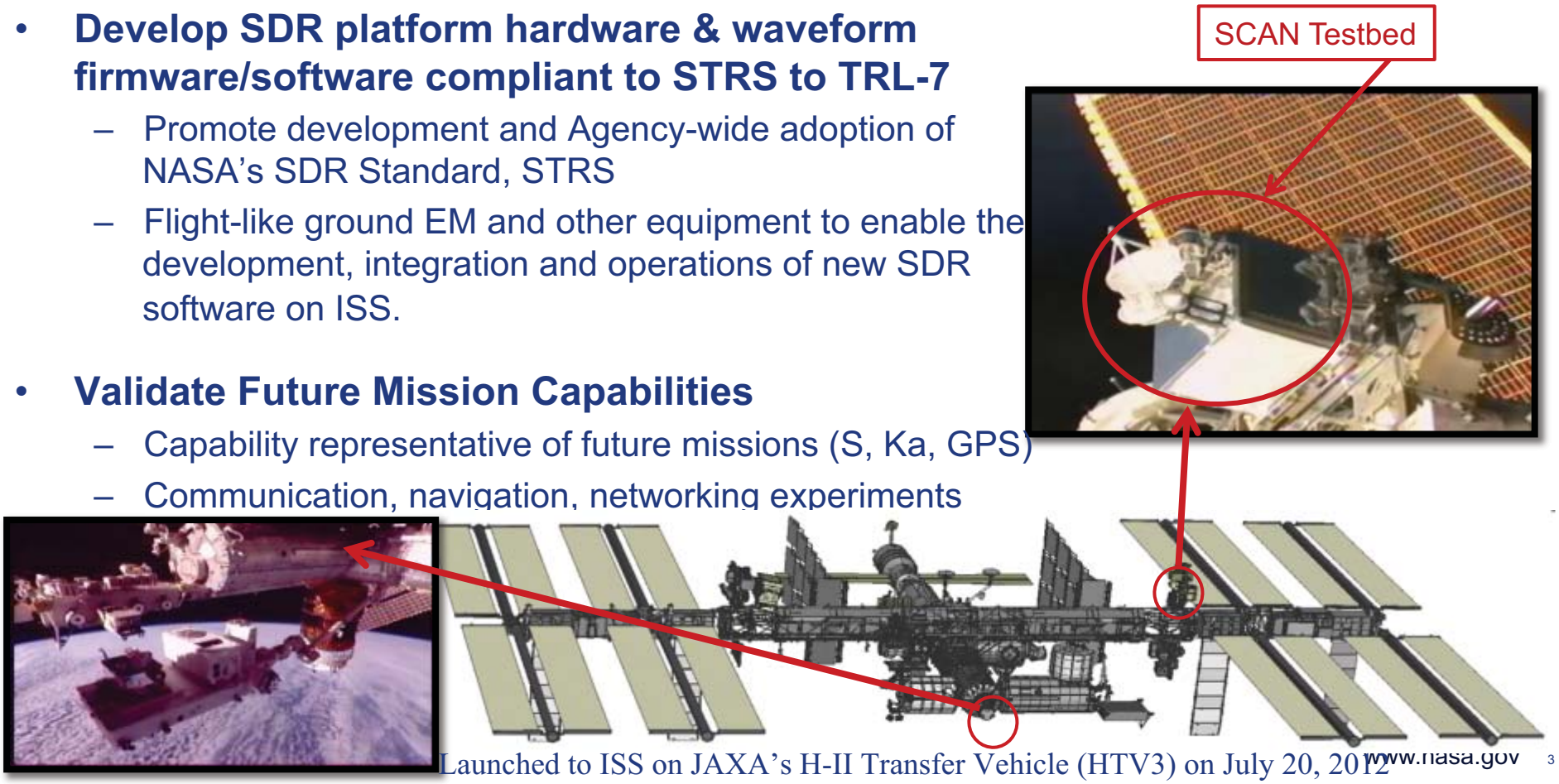
Scope/Purpose of Paper

- **Introduce the Space Communication and Navigation (SCaN) Testbed**
- **Describe the approach used by the team to:**
  - **Qualify three Software Defined Radios (SDR) for operation in space**
  - **Characterize the SDR platform to enable new waveforms**
  - **Reduce risk to upgrade SDRs on-orbit.**
- **Describe unique test approaches for SDRs vs. hardware radios**
- **Discuss space-specific testing**
- **Document lessons learned**

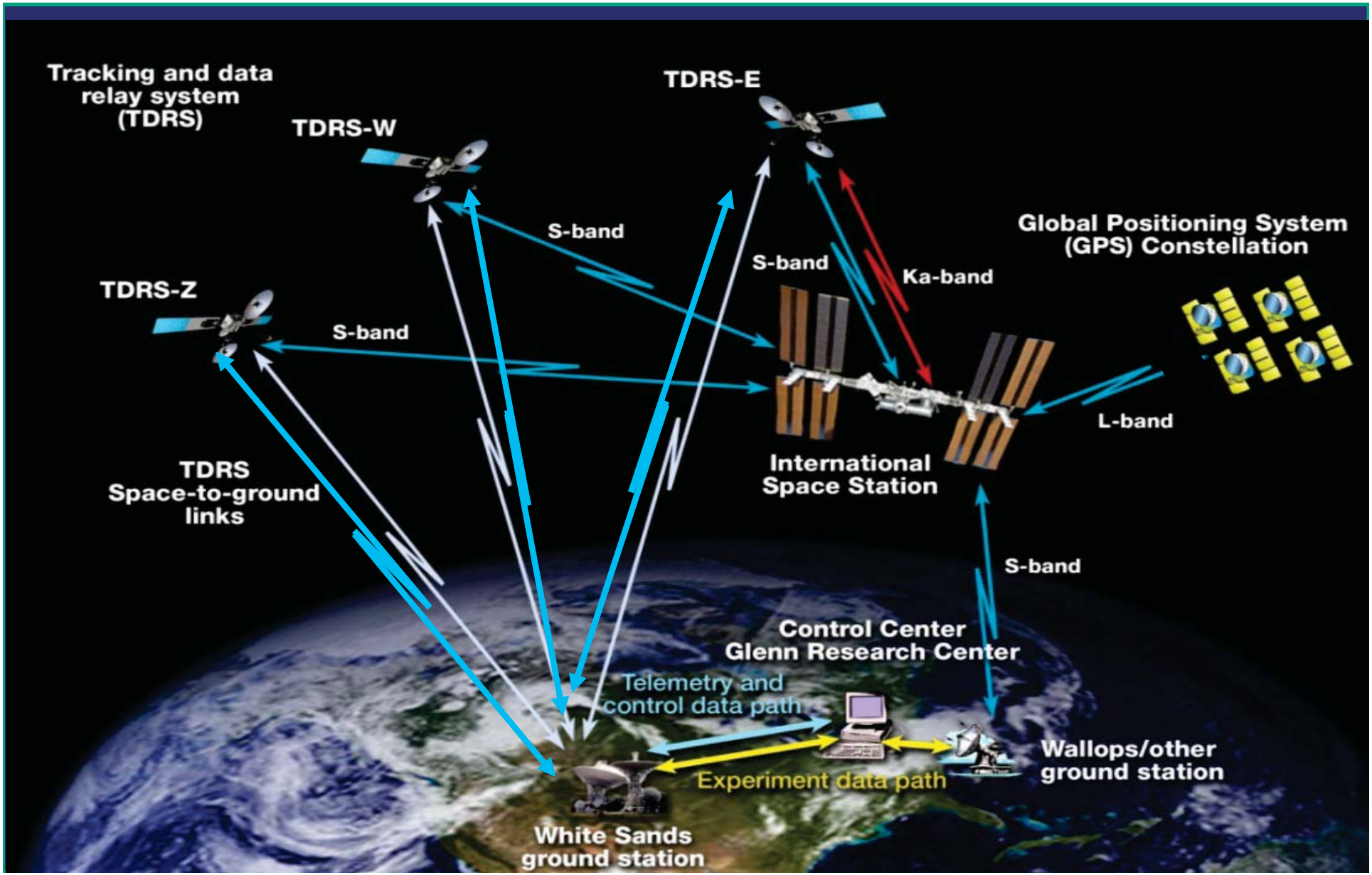
SCAN Testbed Mission Research & Technology Objectives

- **Investigate the application of SDRs to NASA Missions**
  - Mission advantages and unique development/verification/operations aspects
  - SDR reconfiguration, on-orbit reliability
- **Develop SDR platform hardware & waveform firmware/software compliant to STRS to TRL-7**
  - Promote development and Agency-wide adoption of NASA's SDR Standard, STRS
  - Flight-like ground EM and other equipment to enable the development, integration and operations of new SDR software on ISS.
- **Validate Future Mission Capabilities**
  - Capability representative of future missions (S, Ka, GPS)
  - Communication, navigation, networking experiments



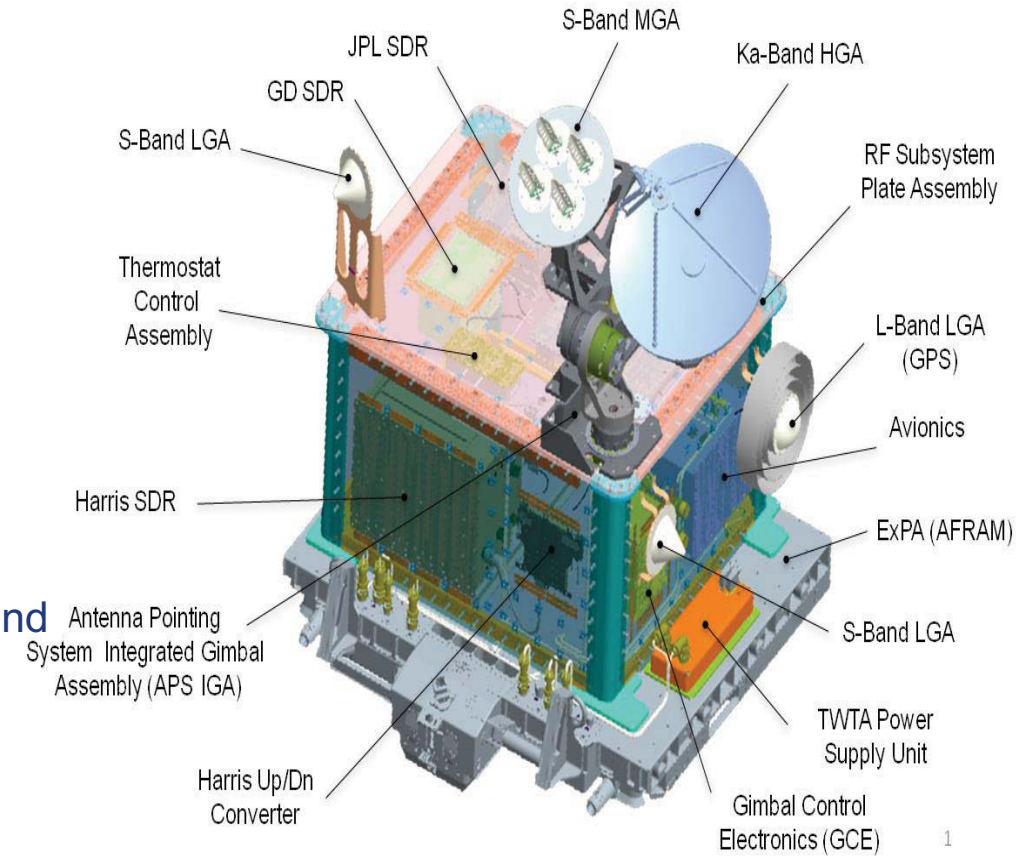
Launched to ISS on JAXA's H-II Transfer Vehicle (HTV3) on July 20, 2012

SCAN Testbed System Architecture



Flight System Overview

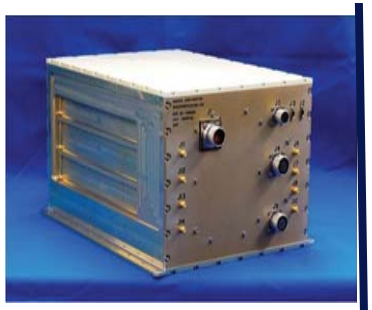
- Communication System
  - SDRs
    - 2 S-band SDRs (1 with GPS)
    - 1 Ka-band SDR
  - RF
    - Ka-band TWTA
    - S-band switch network
  - Antennas
    - 2 - low gain S-band antennas
    - 1 - L-band GPS antenna
    - Medium gain S-band and Ka-band antenna on antenna pointing subsystem.
  - Antenna pointing system.
    - Two gimbals
    - Control electronics
- Flight Computer/Avionics
- Flight enclosure provides for thermal control/radiator surface.



Total mass ~746 lb

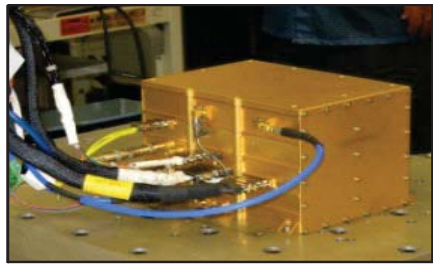
SCaN Testbed SDR Platform Descriptions

Harris



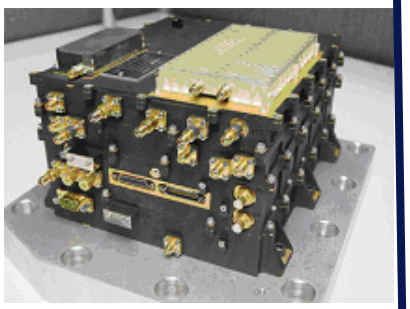
- TDRSS Ka-band (Tx & Rx)
- 4 - Virtex IV FPGAs
- 1 - GFLOP DSP
- AiTech 950 with VxWorks RTOS
- Scrubbing ASIC

General Dynamics



- TDRSS S-band (Tx & Rx)
- 1 - Virtex II Qpro FPGA, 3 M gate
- ColdFire microprocessor w/ VxWorks RTOS
- CRAM (Chalcogenide RAM) (4 Mb)

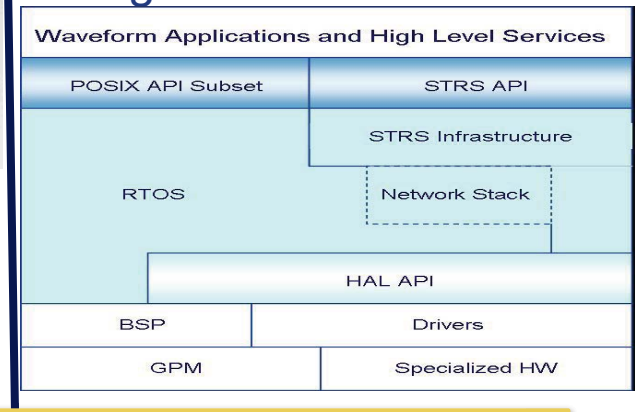
JPL/L-3 CE



- L-band receive (GPS)
- TDRSS S-band
- 2- Virtex II FPGA (3 M gates each)
- Actel RTAX 2000
- Actel AT697 with SPARC V8 Processor using RTEMs OS

STRS

- Advance STRS/SDR Platforms to TRL-7
- Single standard on SDR and WF



- Compliance verified w/
  - -tools
  - -inspection
  - -observation

All SDR tested and flown with TDRSS-compliant waveforms.

SDR Vendor Test Approach

GD and Harris – similar to hardware radio test plan

- Modem performance (Bit Error Rate (BER) vs. Eb/N0 curves)
- Receiver acquisition thresholds
- Transmit power, spectrum, error vector magnitude
- RF module level gain flatness and slope and phase
- Frequency stability

JPL – Unique approach for SDR.

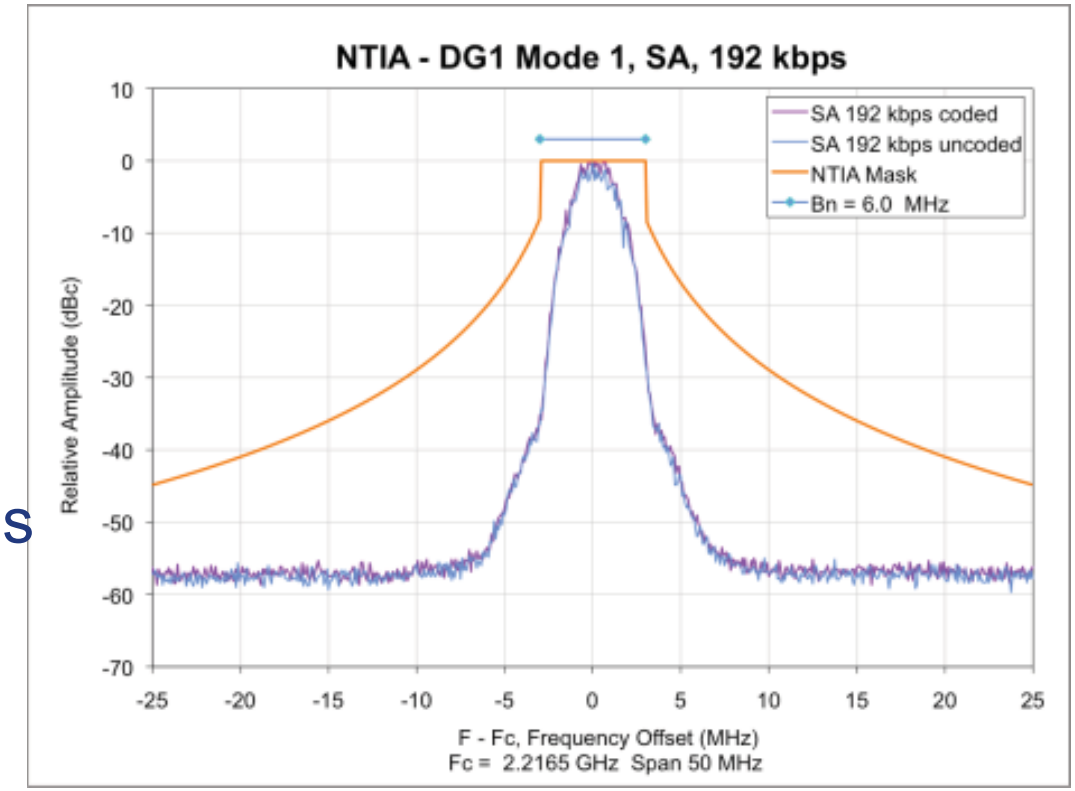
- TDRSS waveform developed in parallel with platform development
- Developed a test waveform to use prior to platform delivery

SDR Unique Test Approach

- Need to consider that future waveforms may operate beyond the bounds of the initial waveform.
  - Develop a “test waveform” that can operate across the range of the hardware capabilities.
    - EMI through hardware receive bandwidth, not just filtered bandwidth
    - Transmit gain measurements across hardware bandwidth
  - Incorporate Bit Error Rate Test functions (PRBS generator and BER checker) into SDRs and Avionics
  - Incorporate platform components available to all waveforms (calibrations, receive power indicators)
- Software / complex electronic development processes
- Approach to update certifications and agreements, such as NTIA and Space Network

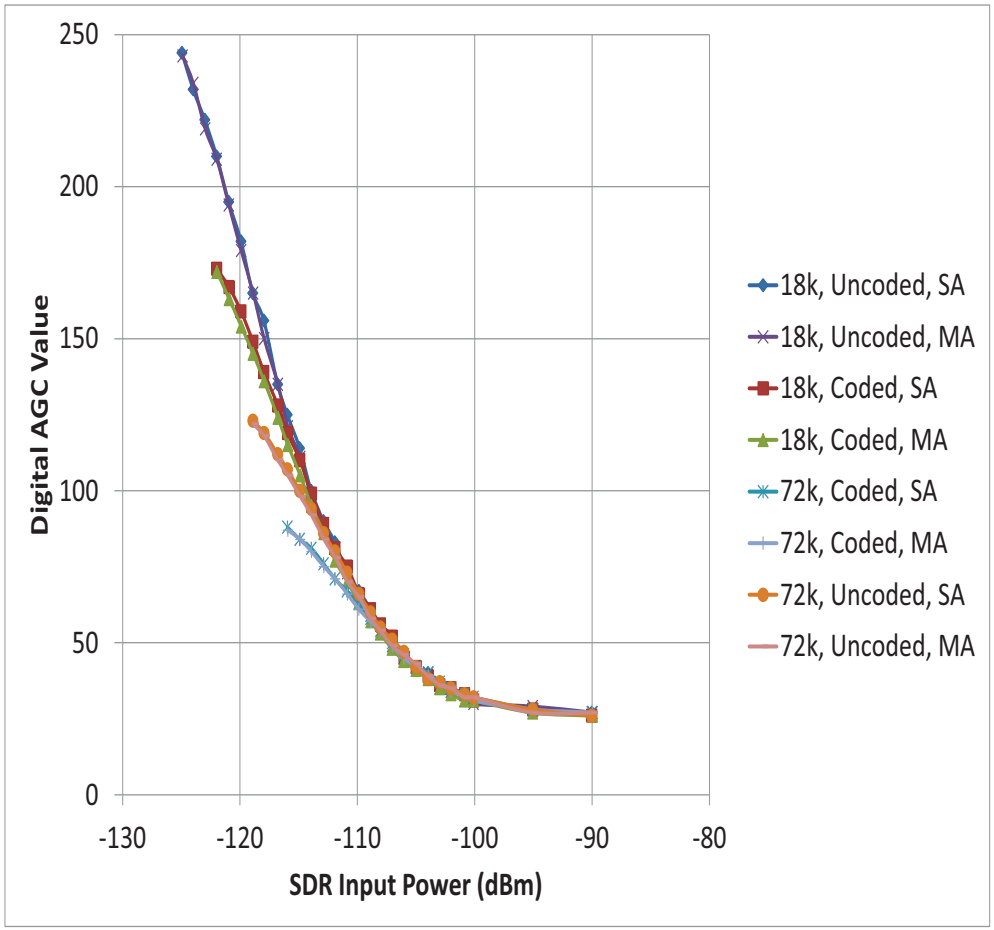
Space-Unique Tests

- Thermal Vacuum - Temperature changes affect performance in the following ways:
  - Path losses through RF components
  - Oscillator output
  - Signal delay through FPGA
- Electromagnetic Interference / Compatibility – future waveform considerations
- Vibration
- Radiation



General Dynamics Test Lessons Learned

- Well-understood input power indication is critical.
  - AGC value used for GD SDR across expected temperature range.
  - Used during EMI to obtain a "non-data aided" receive power indications.
  - Lower AGC (higher input power) than expected indicates interference.
  - Need to incorporate into "platform" function

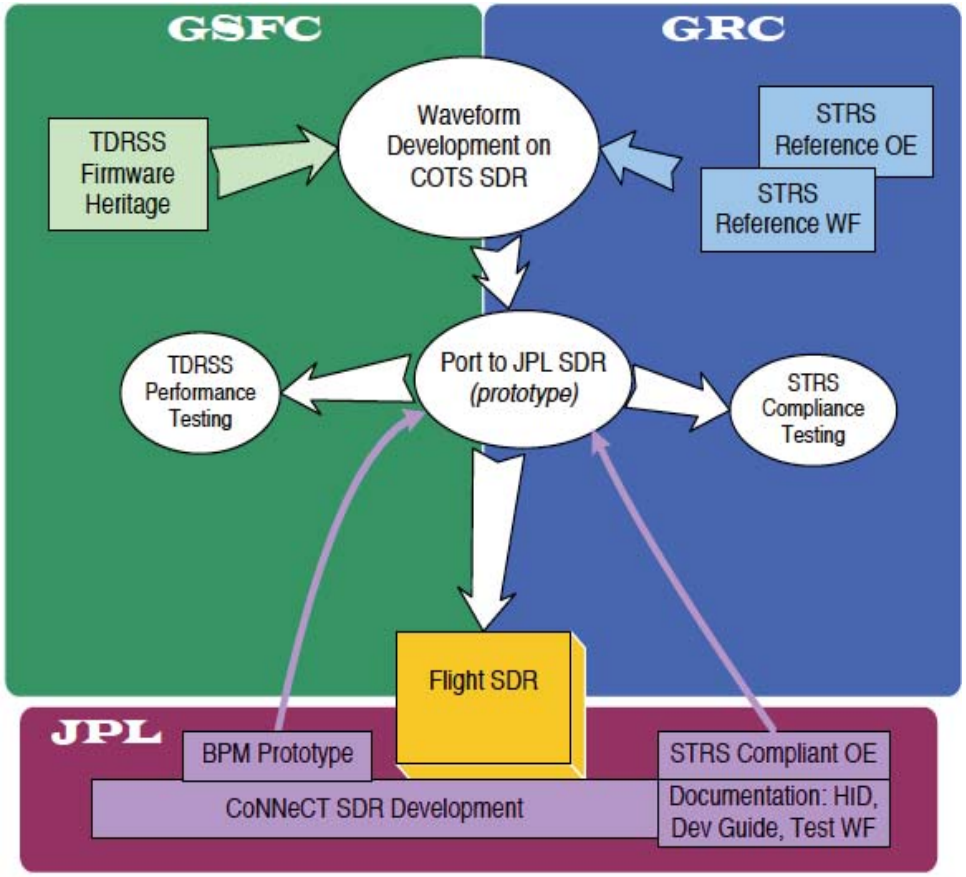


General Dynamics Test Lessons Learned

- Software enables additional flexibility in number of parameters.
  - Adds testing complexity to conduct tests for all combinations
- Ability to upgrade software provided opportunity to fix items that would have affected performance

JPL Development Approach

Parallel, multi-entity development approach for TDRSS Waveform

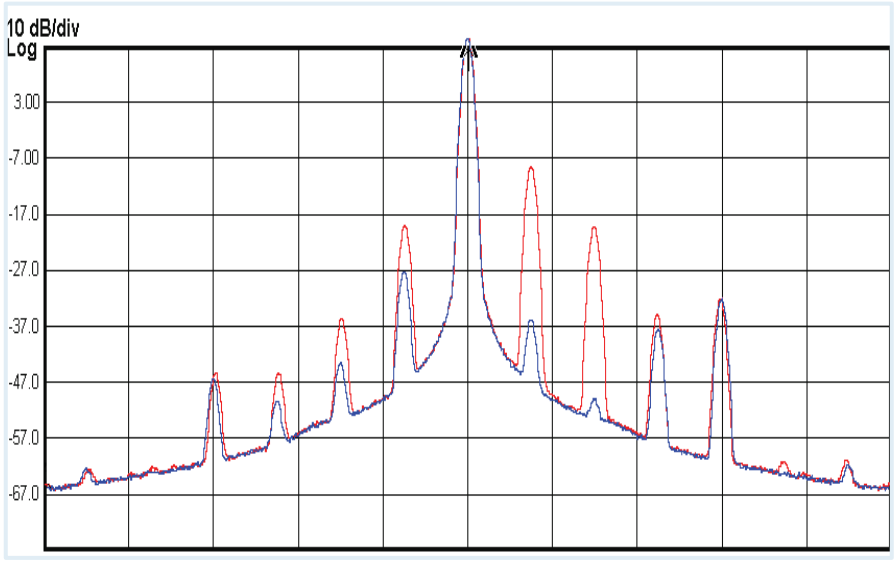


JPL SDR Test Lessons Learned

- Hardware “test waveforms” critical
  - GPS waveform to be uploaded after launch.
  - S-band TDRSS waveform developed in parallel with platform
  - Test waveforms captured ADC samples to confirm hardware performance
- Characterization of flight system across ranges critical. Engineering model unlikely to have similar components.
- No SNR estimated incorporated in waveform. SNR estimator being added. Some type of measured indicator (power levels and performance) at both ends of the links should be considered in all new waveform designs.

JPL SDR Test Lessons Learned

- Improved “test waveform” delivered with platform recommended. Ground test capabilities included in TDRSS waveform
  - Receiver noise figure and gain
  - Vector modulator and oscillator temperature compensation
  - PA compression curves
  - Gain flatness (full hardware bandwidth)



Pre-Flight Data

Harris Test Lessons Learned

- Ability to characterize across frequency very limited (only have one commandable transmit and receive frequency) although other frequencies are being considered for future use.

- Intend to add higher order modulation schemes with TWTA pre-compensation
  - Simulation model developed, including changes in temperature
  - Model could not be verified with waveform limitation

- DSP available in SDR. Testing very limited.

Harris Test Lessons Learned

- Software/firmware updates critical

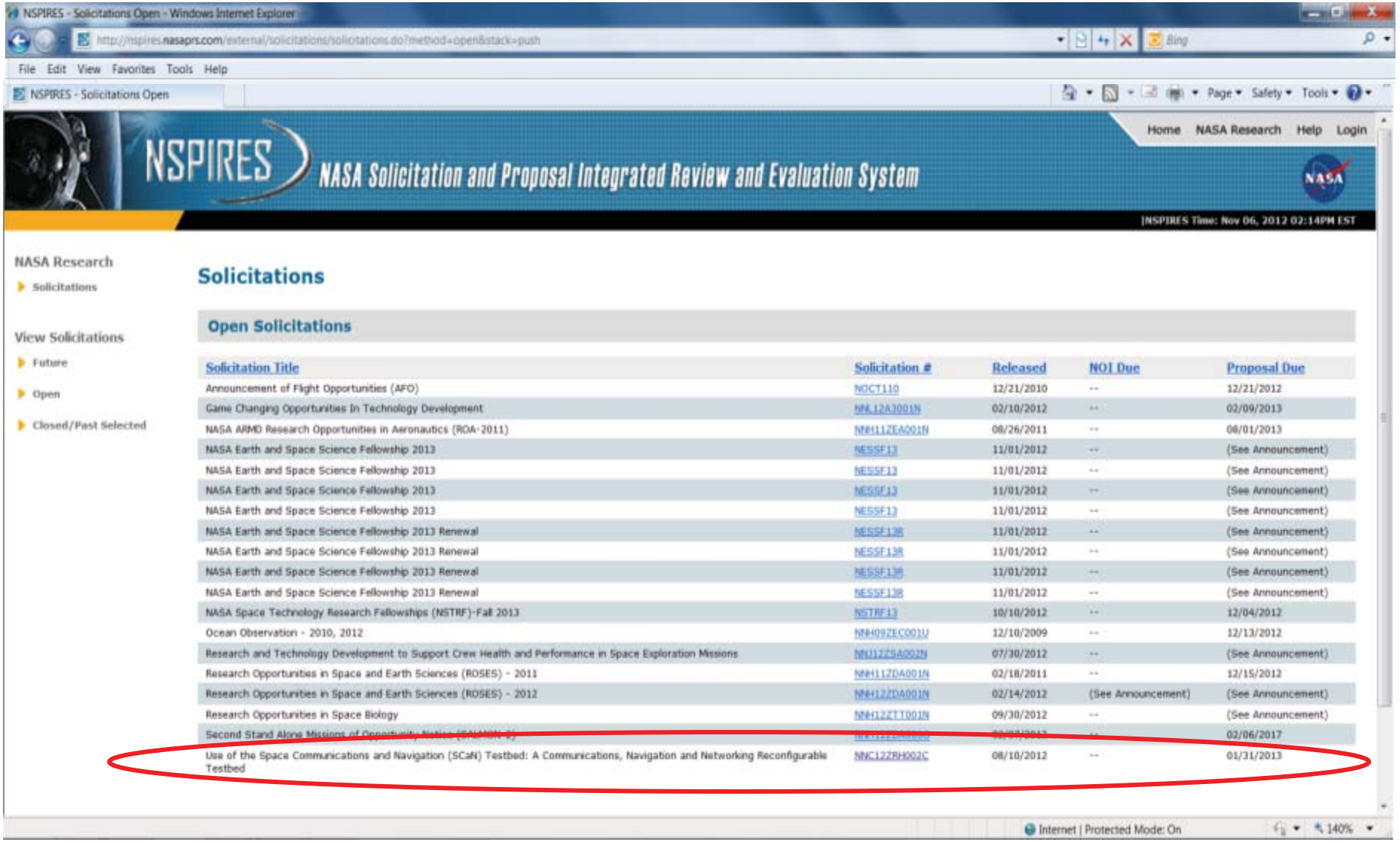
– Very small timing margin in the sequences to set the parameters of the ADC and FPGA led to intermittent high error rate condition
  - Delay value dependent on system voltage and temperature
  - Flight model problem only. Not observed on EM due to differences in components.

– Race condition in commanding sequences caused unexpected reboots
  - Small adjustments in timing algorithm implemented

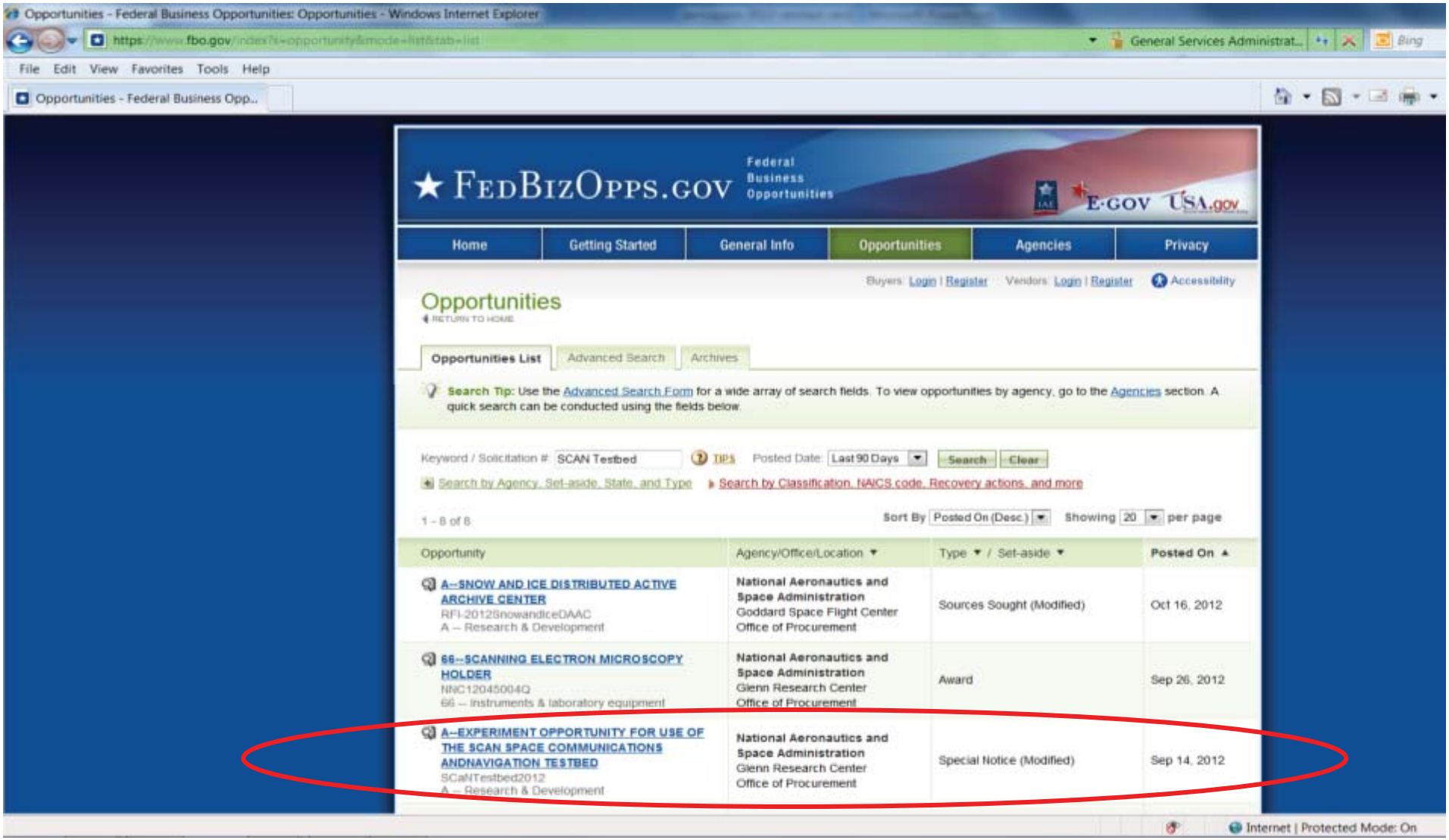
SDR Test Conclusions

- Ability to update software/firmware critical during test activities
- Platform test waveform – independent of operational waveforms - to characterize platform across hardware ranges needed
- Checkout/commissioning activities on-orbit proving value of rigorous system level test, including full characterization.
- True limitation of lack of full test waveforms will be determined with new waveforms

NSPIRES Website



Federal Business Opportunity WebSite



Questions?