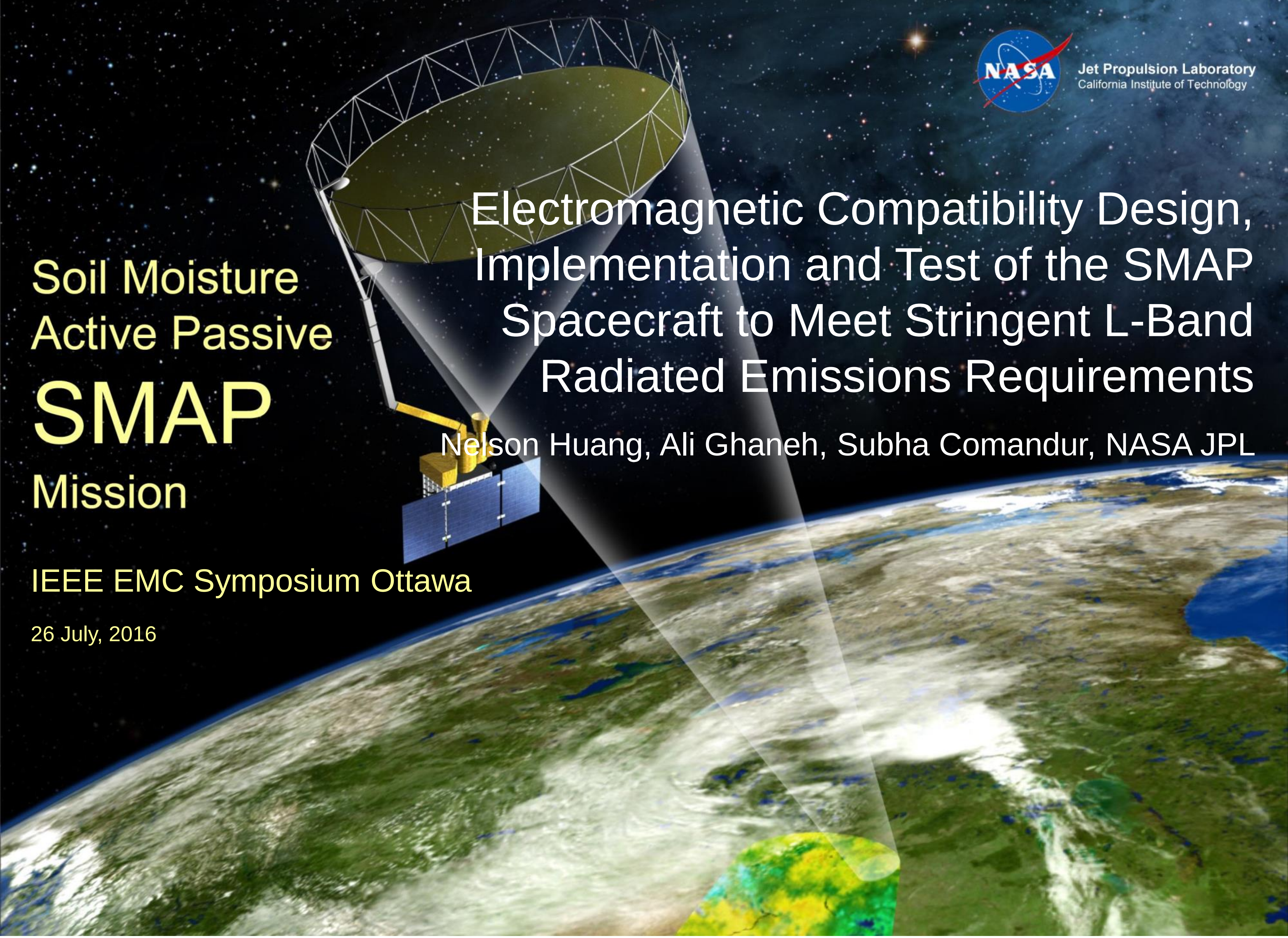

Electromagnetic Compatibility Design, Implementation and Test of the SMAP Spacecraft to Meet Stringent L-Band Radiated Emissions Requirements

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California Institute of Technology

Soil Moisture
Active Passive
SMAP
Mission

IEEE EMC Symposium Ottawa

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Agenda

- Introduction
- Requirements on SMAP Mission
- EMC Mitigation Implementation
- Testing and Results
- Conclusion

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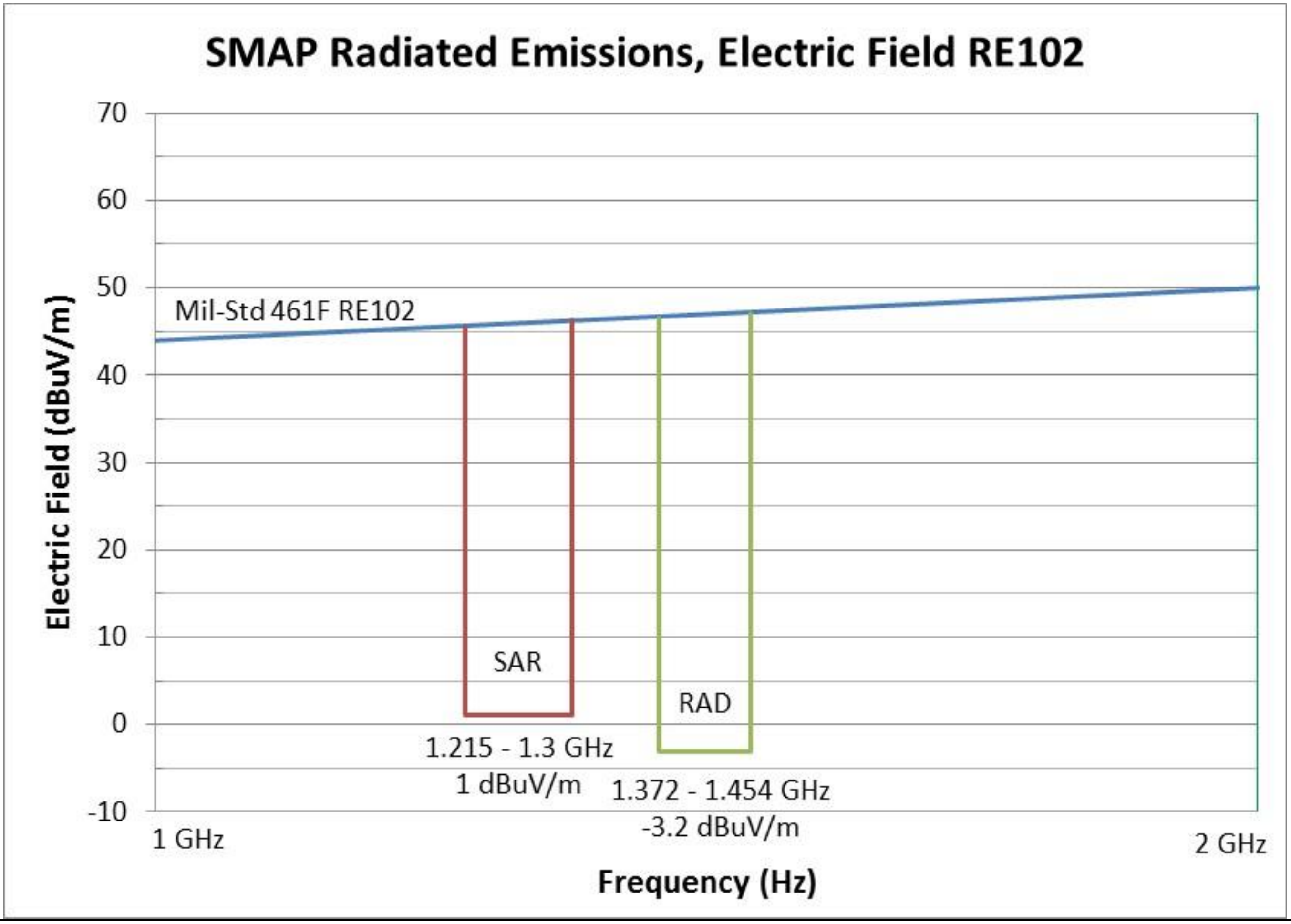
SMAP – Soil Moisture Active Passive

- Earth observing spacecraft launched January 31, 2015
- SMAP provides global measurements of soil moisture and its freeze/thaw state over a 3 year period

EMC Driving Requirement: Radiated Emissions

- Radiated Emissions Electric Field were key driving requirements
- EMC test requirements for subsystems same as system level



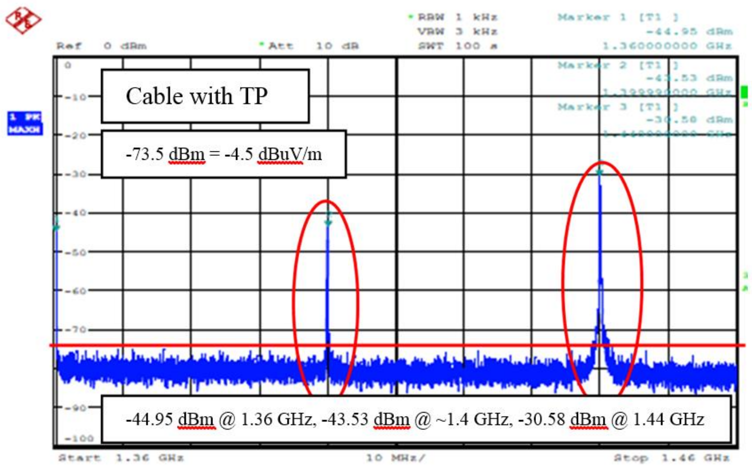
Electrical Interfacing and Grounding Requirements

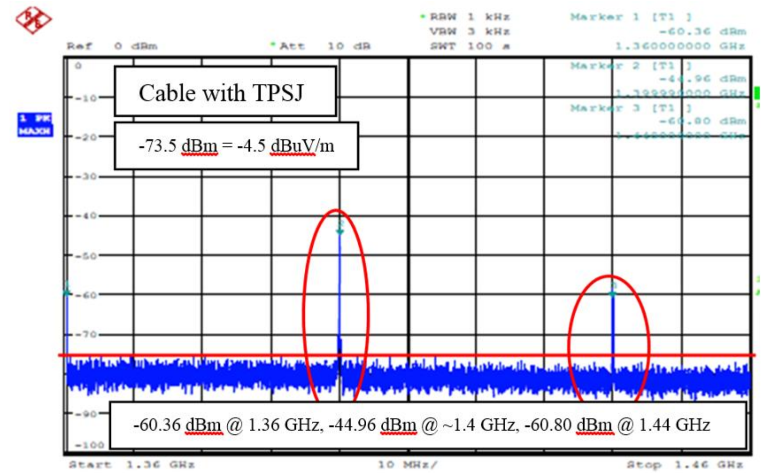
- Electrical Interfacing and Grounding Requirements were drafted and levied early in the project to:
  - Provide a system reference (ground) plane for electronic chassis and circuits
  - Prevent DC currents from flowing through structure.
  - Provide for magnetic field cancellation within cable harness bundles,
  - Reduce conducted and radiated emissions by minimizing common-mode current
- The SMAP spacecraft used the Single Point Grounding (SPG) method.

- Note: The SMAP Spacecraft was not a Faraday Cage. Every subsystem was required to address best practices for EMC and meet requirements at their level, including harness.

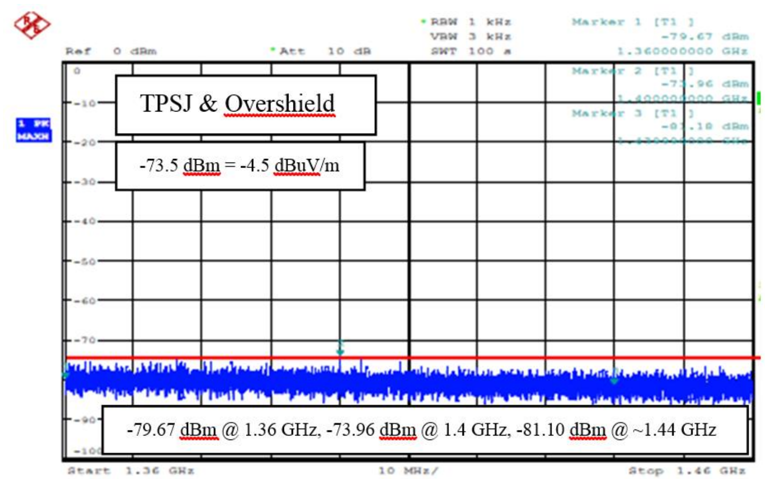
SMAP System Cabling Implementation

- Wire Shielding and Cable Harness Overshield Approach



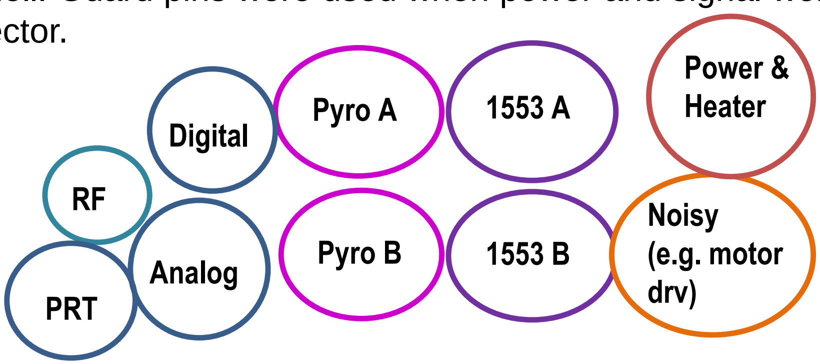


- Using Twisted Pair (TP) only, the emissions were 40db above spec.
- Using Twisted Shielded Jacketed Pairs (TPSJ) only, the emissions were 28db above spec.
- **Using TPSJ + EMI Tape, the emissions were within spec when the box connector ends were 360 degree terminated.** This was baselined for all harnesses on the sensitive Radar and Radiometer Instruments, including Power.
- On the spacecraft, all sensitive signals were TPSJ+overshield. Power cables were only TP+overshield.

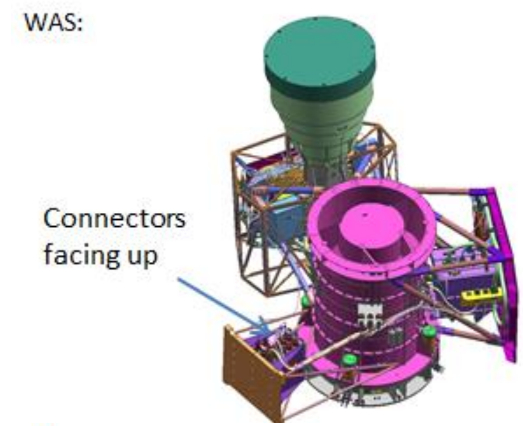


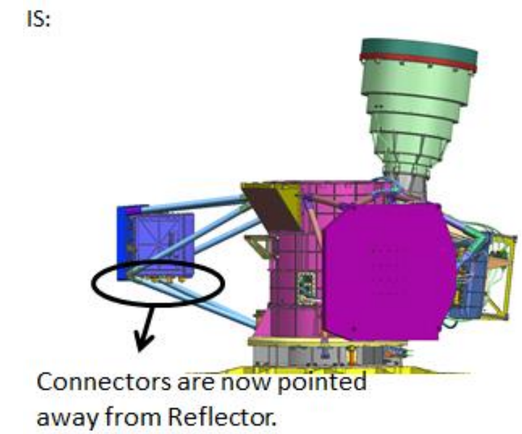
Harness EMI/EMC Best Practices Implementation

- **Every harness was required to be a faraday cage.**
  - Achieved with overshield on every harness, **360' termination** of inner shields and overshield with backshells at both ends and avoiding use of drain wires. Group straps were provided across mechanisms and composite structure.
- Due to impacts of overshielding cables in mass, volume, cost, and schedule during fabrication, a trade of shielding options (Copper braid, Copper-Nickel Fabric tape, Copper foil etc) was performed.
  - Results showed that at **L-band, EMI Fabric tape was the best option**.
- **Circular connectors** were used to the maximum extent possible on the Instruments since they provide better shell continuity than micro-d and D-sub connectors. An electronics box for spin mechanism and motor drives used filter pin connectors.
- **Pin assignments** were such that for sensitive signals and controlled impedance wire, high and return were on adjacent pins and closer to the outer periphery of the shell. Guard pins were used when power and signal were in the same connector.



Signal Separation in Harnesses





Mechanical Configuration took into account connectors as source of leakage. An instrument box on SMAP was rotated **to point the connectors away from the feed horn/reflector.**

Heaters and PRT Implementation

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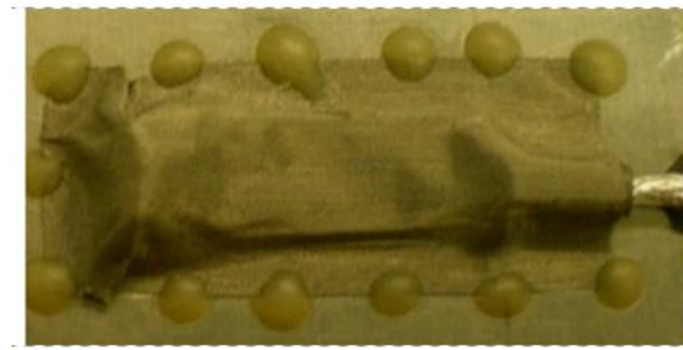
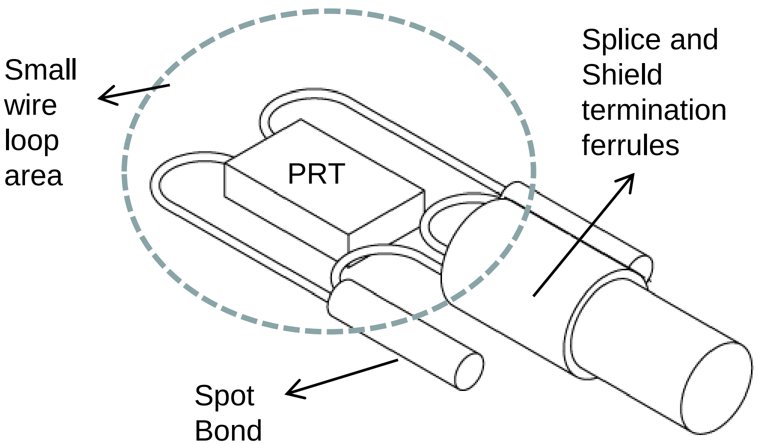
- On SMAP, we determined which PRTs and Heaters needed to be under a faraday cage, based on factors such as whether the PRT/Heater was on during science operations, and proximity of these thermal hardware to sensitive boxes.
- EMI tape covered the PRT/Heater, the wire shield termination ferrules and overlapped with the EMI tape along the length of the cable.

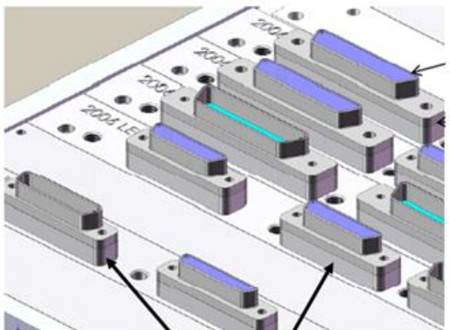




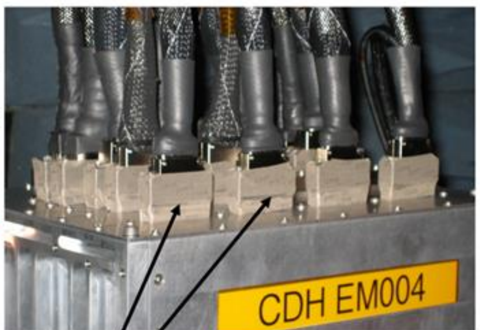
This minimizes the amount of inductive noise coupling between the circuit and surrounding cabling by decreasing the area of the receptor loop i.e. total area enclosed by current flow.

Innovative Packaging Considerations

- SMAP Command Data Handling (CDH) Subsystem leveraged heritage
- Identified risk and convened EMC Working Group to mitigate risk
- Implemented JPL unique raised pedestal packaging approach and conductive tape to mitigate radiated emissions from D sub connectors.
- Implemented cover tape to seal gaps between card slices.



Pedestals



Connector Backshell + Pedestals wrapped with Tape

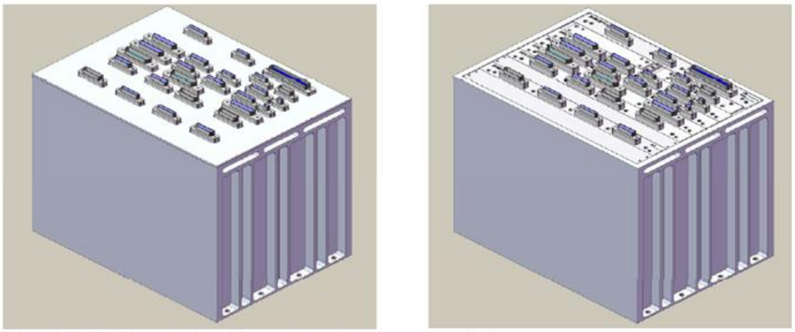
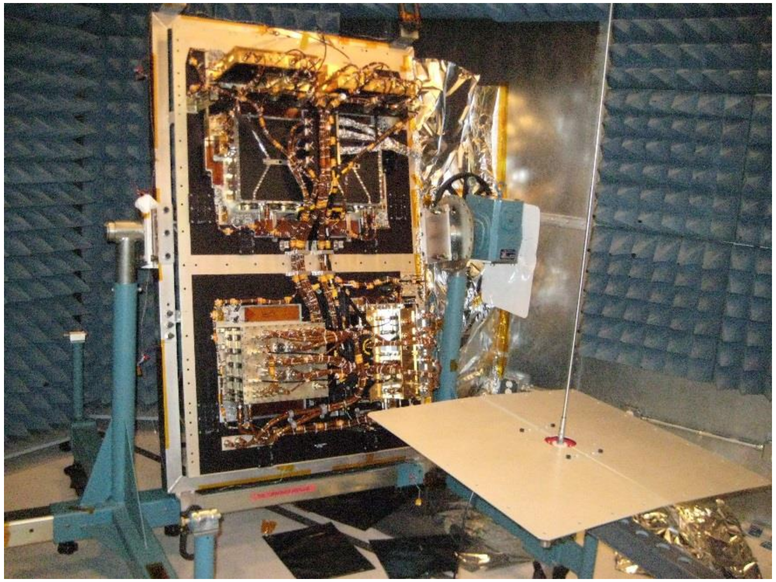
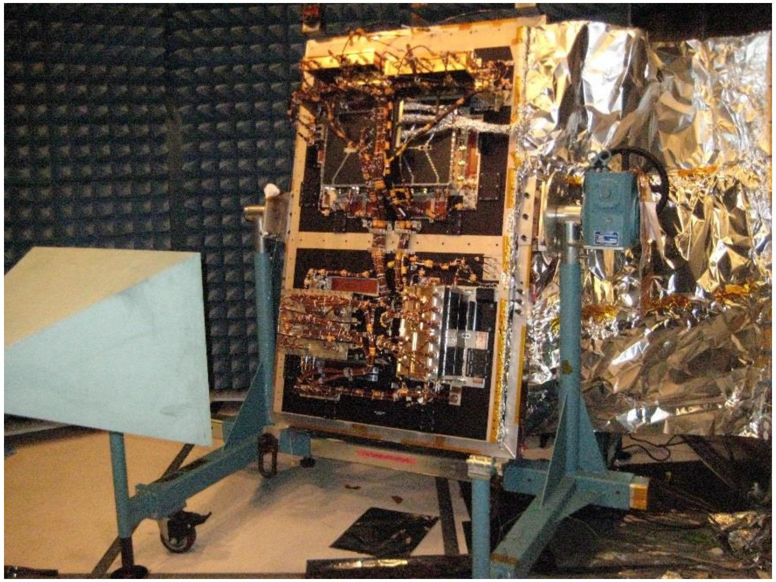


Fig. 4. CDH model with and without cover plate.

SAR Subsystem EMC Test

- New designs incorporated EMC packaging best practices, i.e. circular connectors, gaskets across top cover seams
- SAR test modes included, receive only low and high resolution, transmit single frequency and multiple frequencies





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SAR Subsystem EMC Test Results

Receive Mode, Low Resolution Data

Figure 139: SMAP SAR RE02 Data, L-Band Notch from 1.215 GHz to 1.455 GHz, Pos 1 V-Pol SAR in Receive Only Mode with 0% High Resolution Data

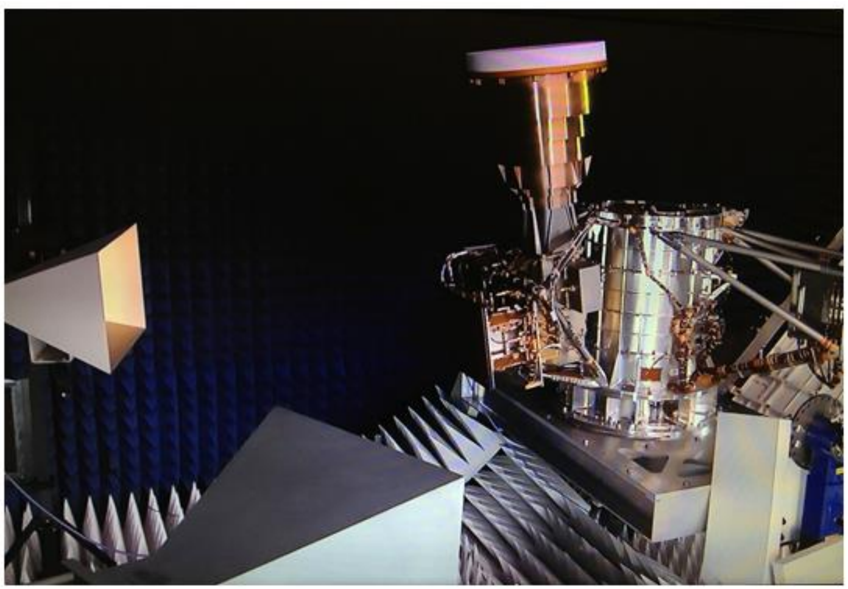
Receive Mode, High Resolution Data

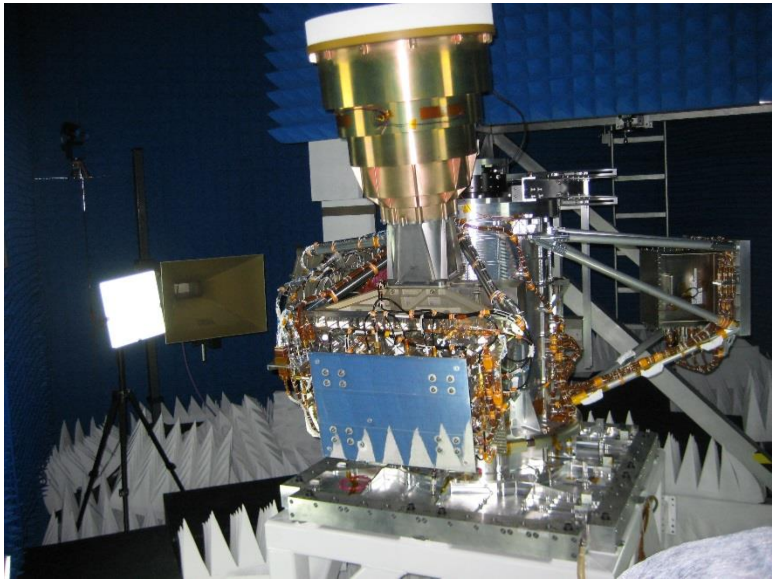
Figure 140: SMAP SAR RE02 Data, L-Band Notch from 1.215 GHz to 1.455 GHz, Pos 1 V-Pol SAR in Receive Only Mode with 100% High Resolution Data

- ~6 dB non-compliance @ 1.22 GHz and ~2 dB non-compliance @ 1.44 GHz was assessed for impact and waived

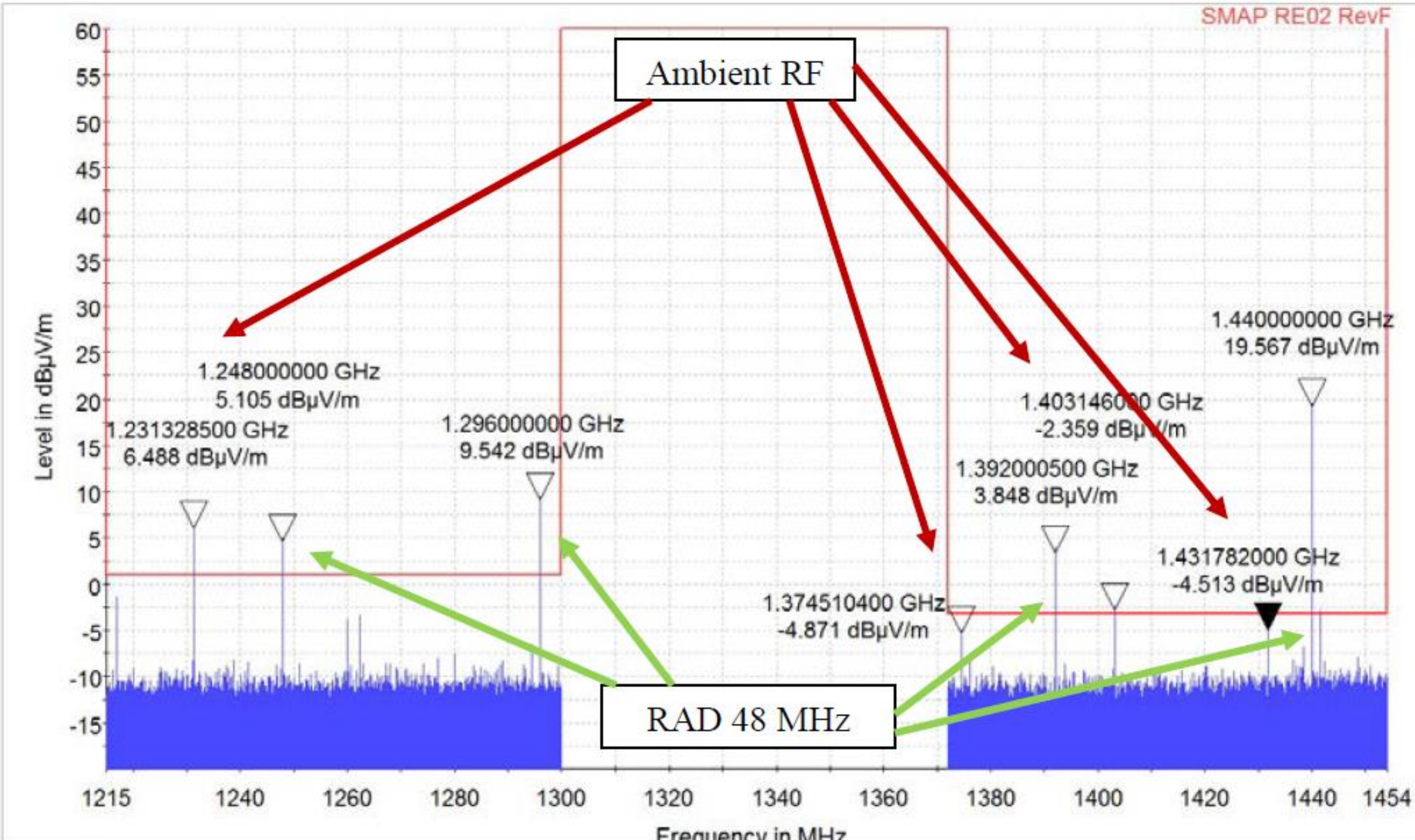
SMAP Integrated Instrument EMC Test

- Integrated Instrument consisted of 1) RAD, 2) SAR, 3) Spin Hardware
- Pass/Fail Criteria was Instrument self-compatibility
- Radiated Emissions Data measured in background to provide added info





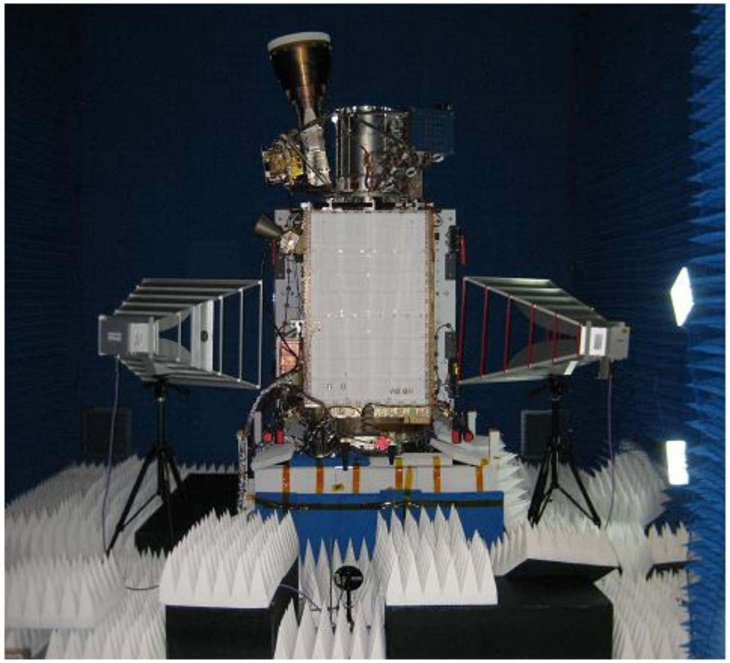
Integrated Instrument Spun Test Results

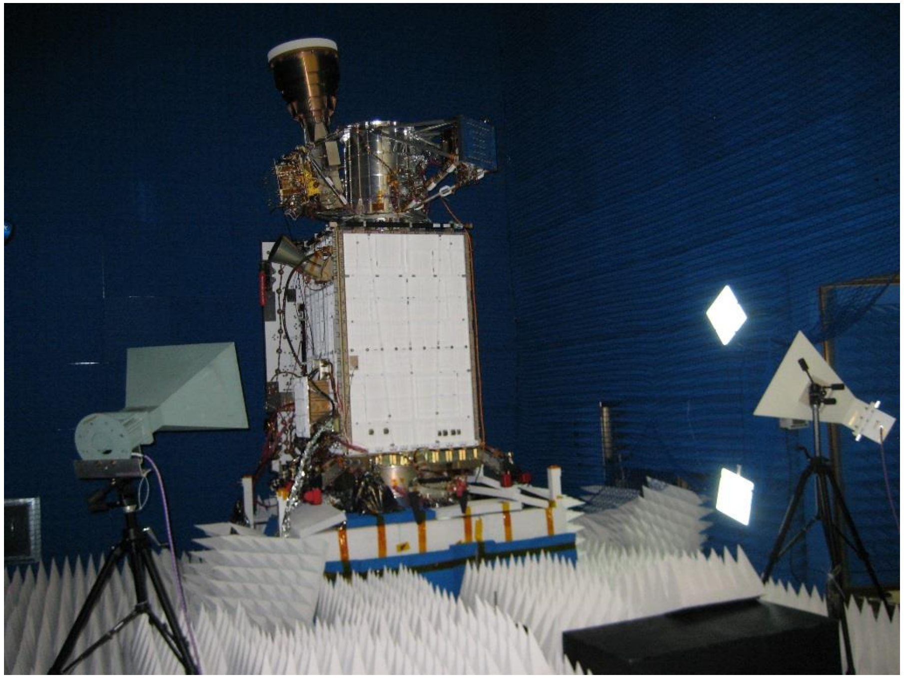


- Instrument demonstrated self-compatibility and met test objectives
- Note: 48 MHz Harmonics due to RAD @ 1.248, 1.296, 1.392, 1.44 GHz
- Ambient RF due to EGSE @ 1.231, 1.375, 1.403, 1.432 GHz

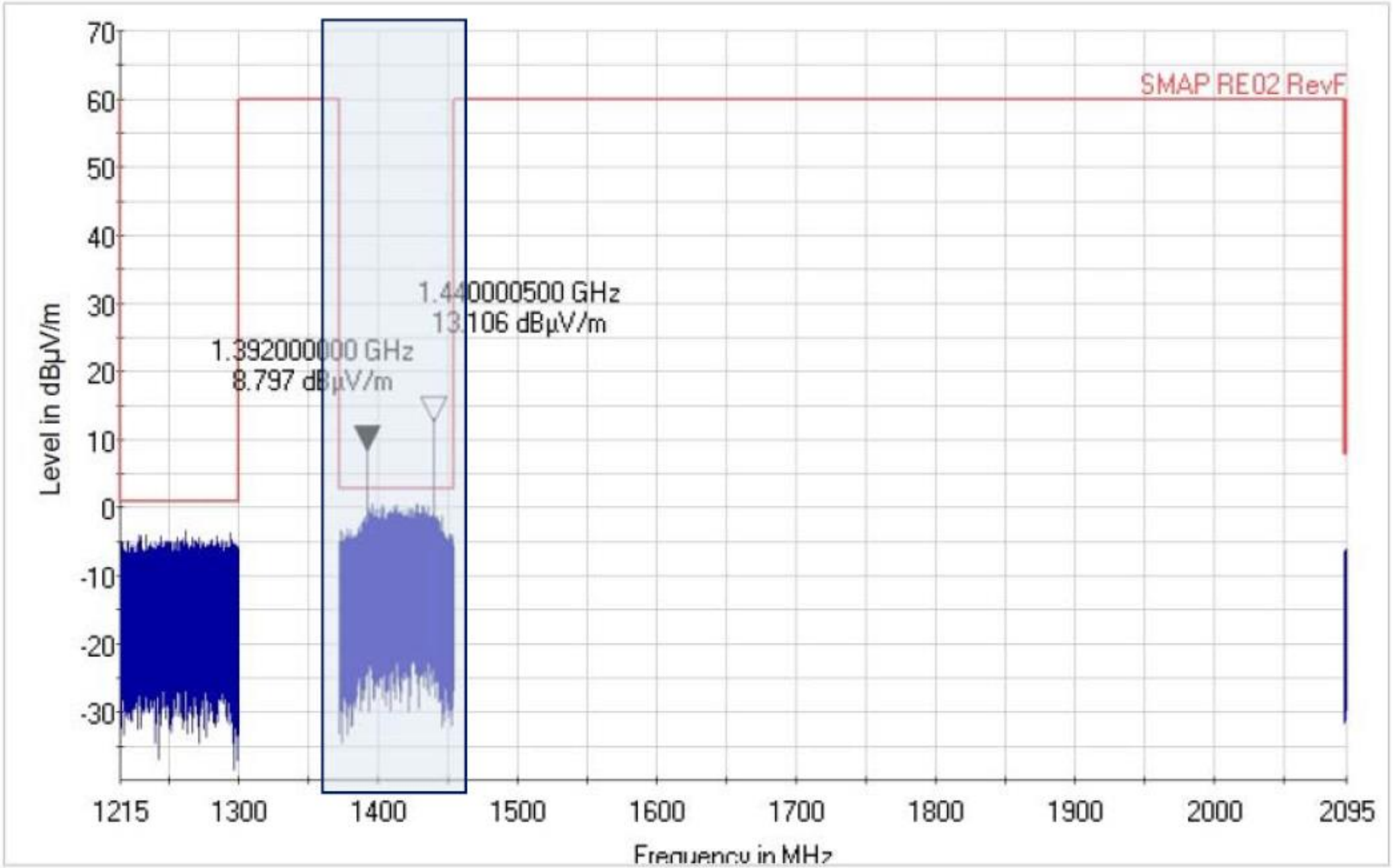
SMAP Observatory EMC Test

- SMAP Observatory passed Launch RE and RS requirements
- Demonstrated Self-Compatibility and met Plugs Out objectives
- Dry ran flight launch scenario up to ascent during Plugs Out test





SMAP Observatory EMC Test Results



- Observatory self compatibility radiated emissions data
- Note: 48 MHz Harmonics due to RAD @ 1.392, 1.44 GHz
- During SAR transmit mode, filter applied to attenuate 1.215 – 1.3 GHz

Summary

- The SMAP EMC Experience
  - Established mature requirements early in the program
  - Implemented EMC mitigation in the design when possible
  - Performed EMC tests on subsystems and during multiple stages at the system level

- Lessons learned,
  - Perform EMC testing as early as possible to reduce EMC risk, even if heritage data demonstrated compliance.
  - EMC collaboration with SMAP design engineers early in the program led to impactful EMC design features for system level cable harnessing and packaging design features for heritage hardware.
  - Wise selection of subsystem clocks/operating frequency was crucial. Violating frequency harmonics ended up falling outside the actual science passband frequencies.