# Design Approach and Lessons Learned for Challenging EMI Requirements


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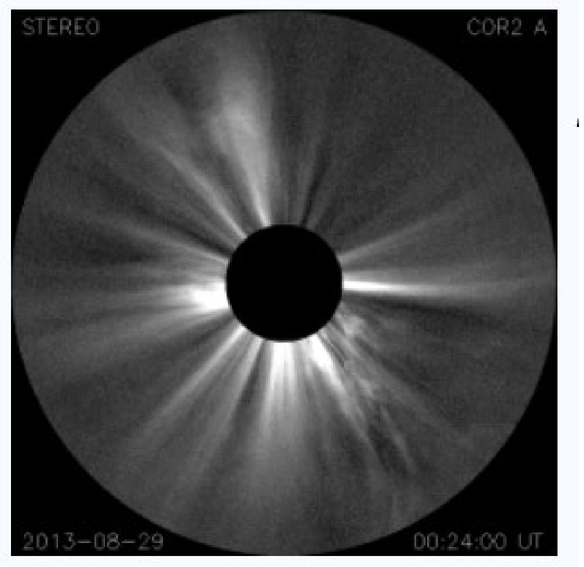
# Presentation Overview

- The Naval Research Laboratory (NRL) Compact Coronagraph (CCOR) instrument was a late addition to the National Aeronautics and Space Administration (NASA) Geostationary Operational Environmental Satellite (GOES-U) Spacecraft
- Accommodating the baseline design of CCOR’s power system electronics was not feasible due to physical constraints on the GOES-U spacecraft’s Solar Pointing Platform (SPP)
- CCOR had to reduce the Power Supply size while also improving performance to meet unusually challenging Electromagnetic Interference (EMI) requirements
- This presentation outlines the approach used by CCOR and CCOR-2, which may be applicable to future instruments ridesharing on other spacecraft
- Emission data from CCOR will also be shared and lessons learned regarding repeatability between CCOR and CCOR-2

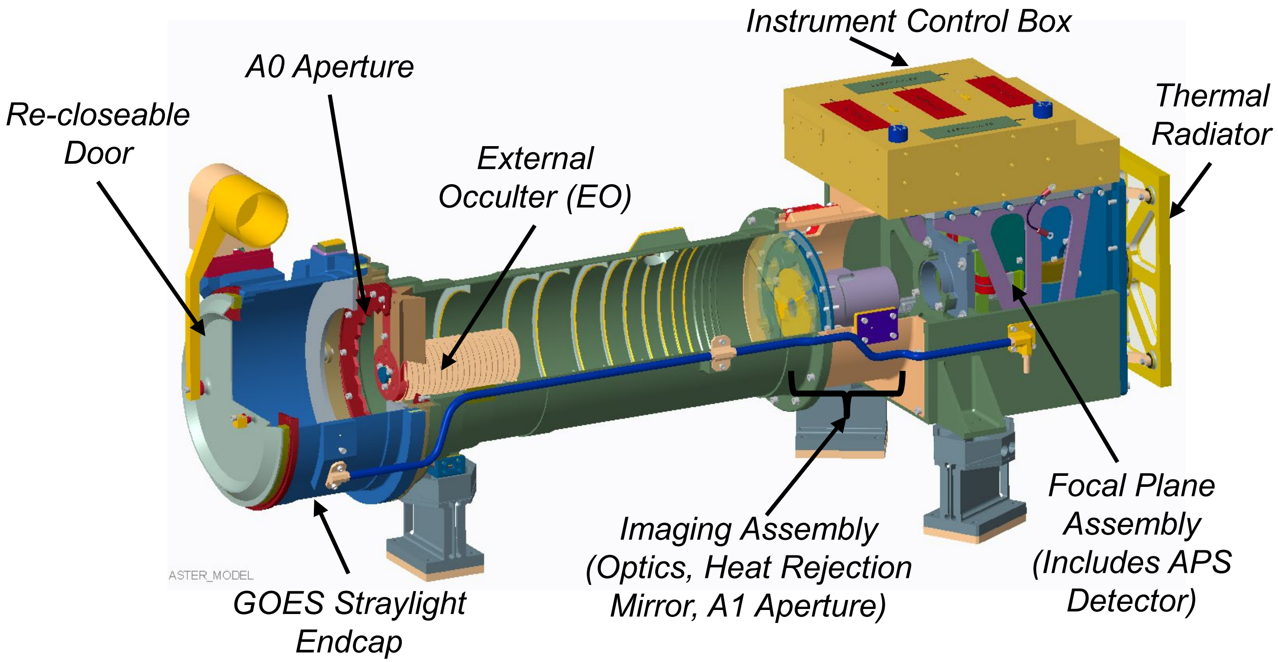
# Presentation Goal

- To provide a high-level outline for how CCOR met challenging EMI requirements
- To demonstrate that challenging EMI requirements can be met with relatively unsophisticated techniques
- To share data and strategies that can be used as reference for future programs to mitigate EMI risk
- To highlight the success of some unconventional design choices that helped CCOR reduce mass
- To share lessons-learned regarding repeatability and failure resolution

# CCOR (Compact Coronagraph) Overview




***SECCHI/COR2 CME Observations***

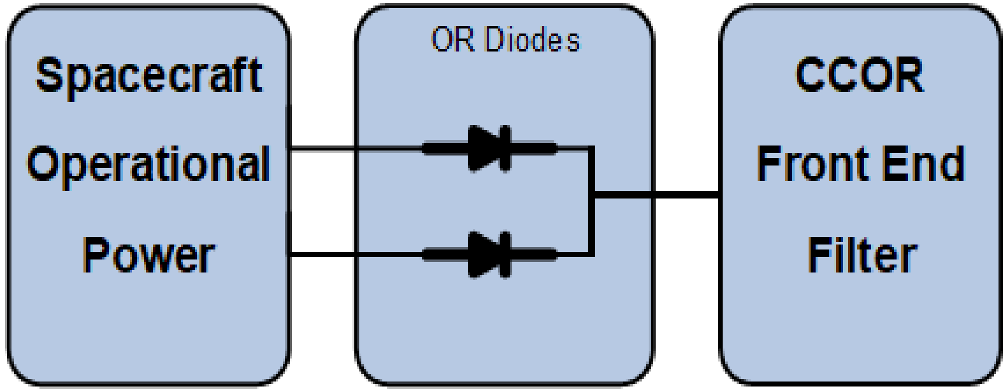



- Solar coronagraphs are specialized telescopes that image the corona by creating an artificial solar eclipse.
- Wide field and broadband visible light coronagraphs efficiently detect CMEs.

- CCOR and CCOR-2 are:
  - Single stage coronagraphs
  - Adapted specifically to the detection of brightness variations of CME plasma density increases.

# Design Overview

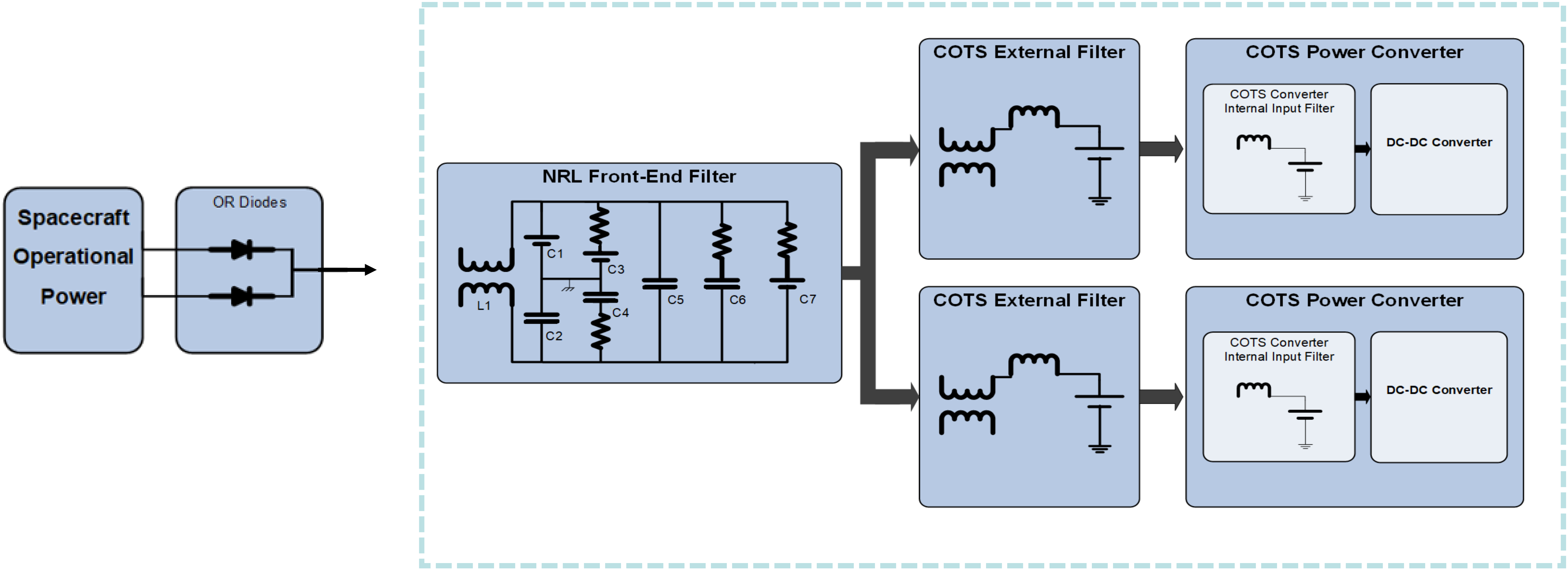
- CCOR is connected directly to the Spacecraft operational power interface
  - There is no command interface or switching
  - The operational power is directly connected to CCOR's front-end filter
  - There is a "Diode-OR" configuration for tying the primary and redundant operational power feeds within the CCOR Power Supply
- The design approach required careful coordination between CCOR and Spacecraft bus
  - CCOR provided input impedance models
  - The Spacecraft provided details of the power bus rise-time which CCOR emulated in their EGSE



# Power Converter Overview

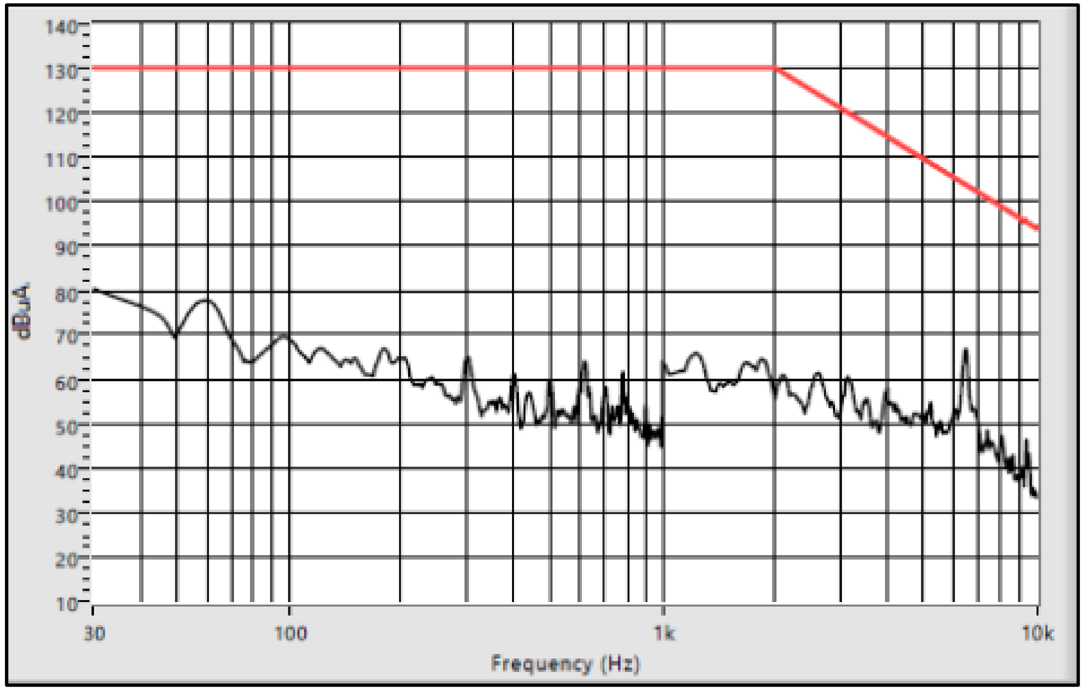
- CCOR's primary power system utilized S2800 series power converters and their corresponding SF461 EMI filters (made by Infineon)
- NRL confirmed the emission and filter performance with bench testing
- Despite exceeding expectations from advertised data the filters were not adequate to meet the highly demanding requirements of the Spacecraft
- NRL worked with Infineon (sharing SPICE models) of filter designs and was able to design additional front-end filtering
    - This enabled both parties to do impedance and stability analysis
    - EM designs were built and formally tested for C.E. and R.E.

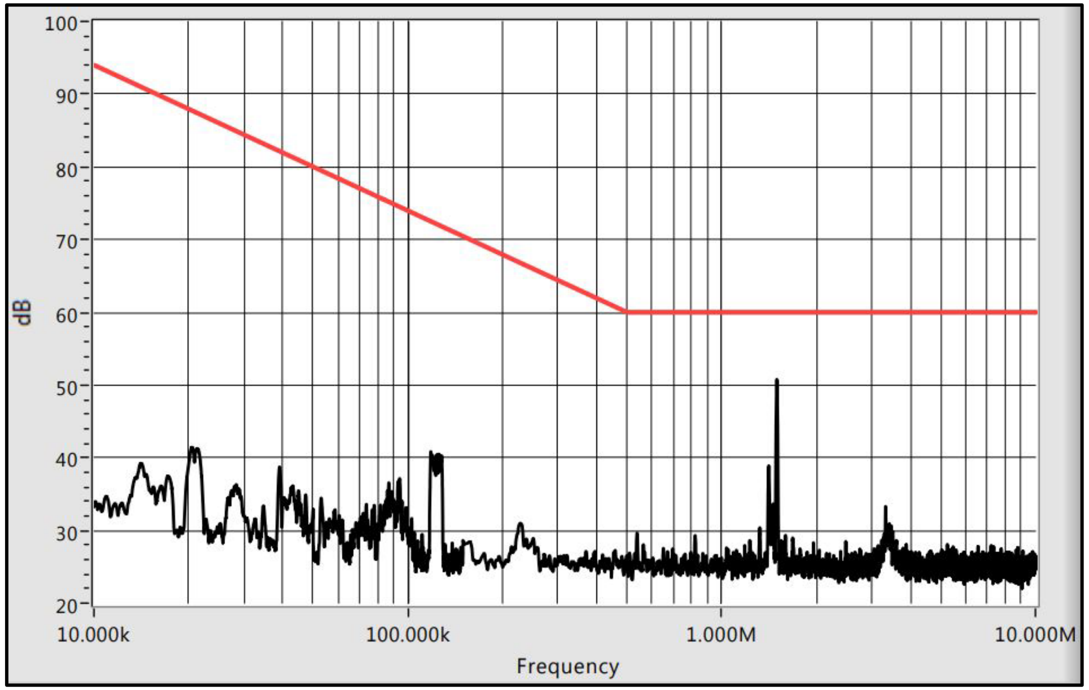
# Front-end Electronics and Filter Design



# CONDUCTED EMISSIONS

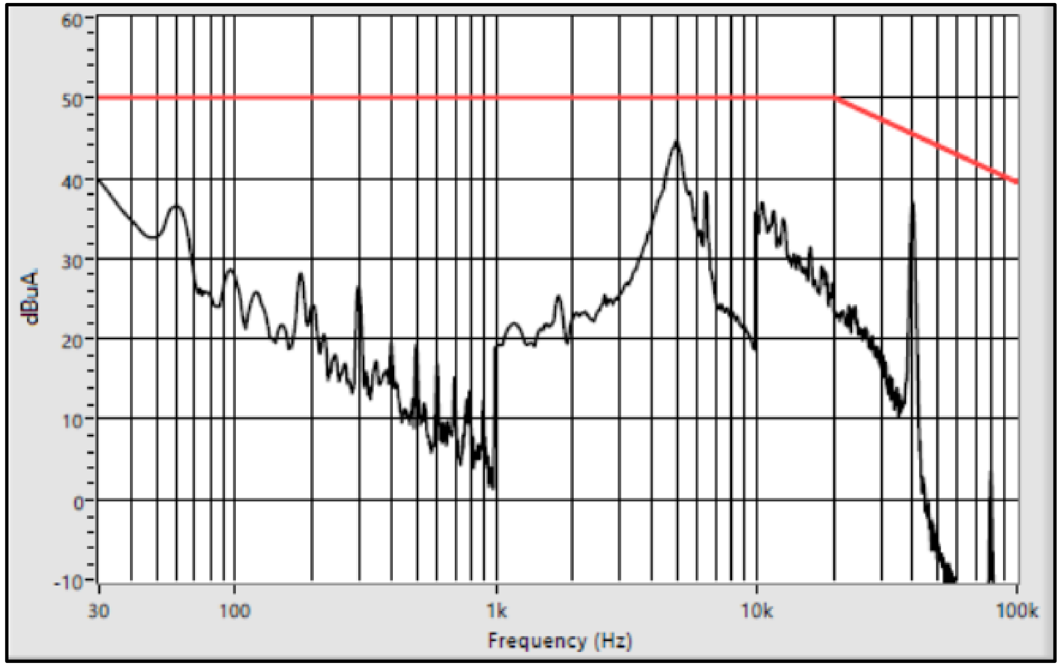
# CCOR-1 Conducted Emission Examples: Differential Mode

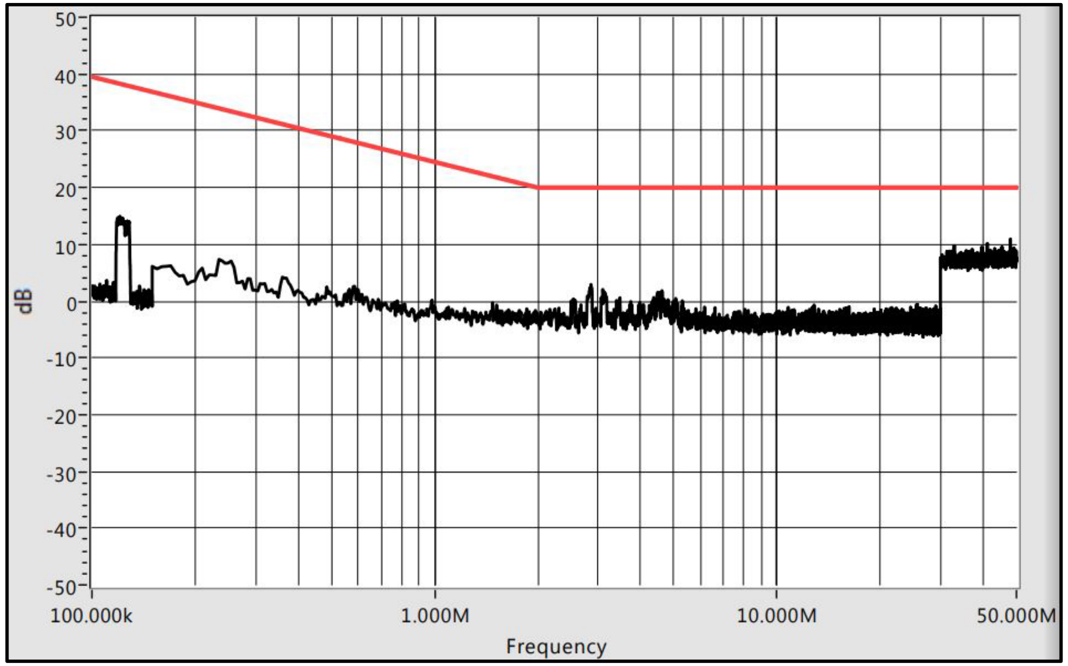



- The differential mode requirements for this program were fairly standard, but results are included for additional context

# CCOR-1 Conducted Emission Examples: Common Mode

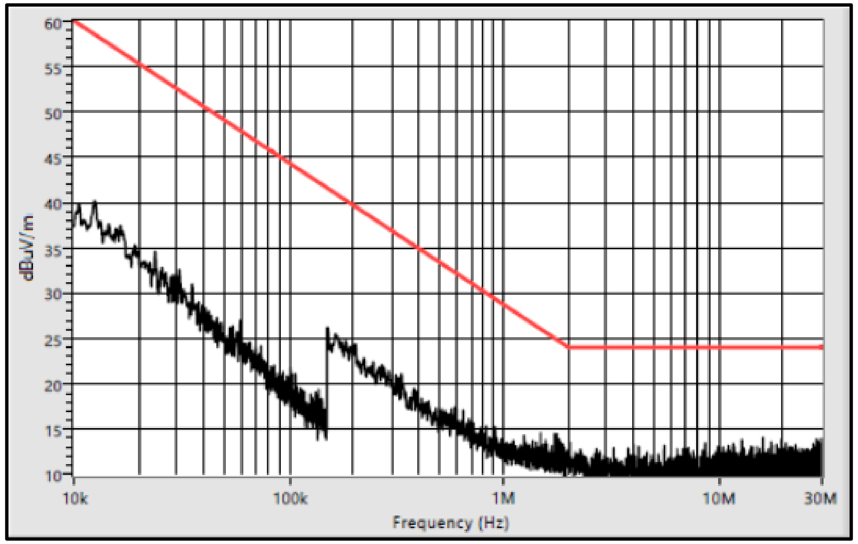


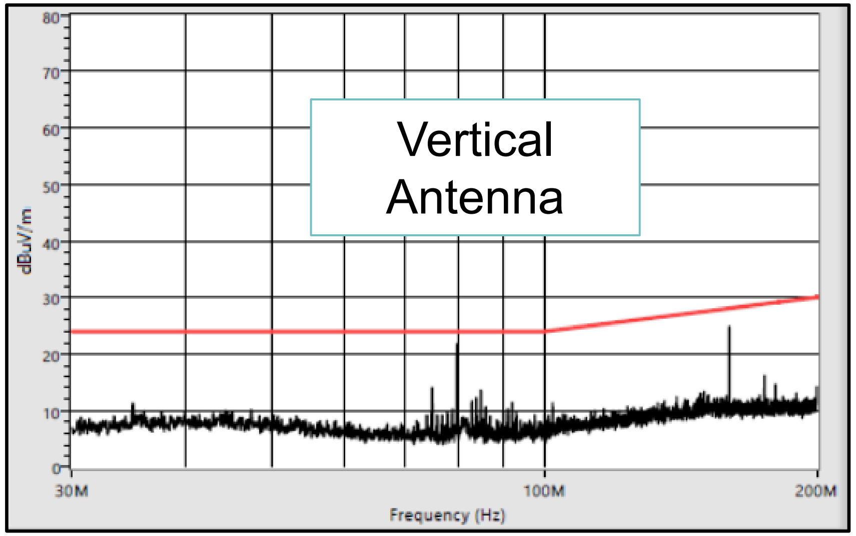




- The source of the 5kHz peak was not identified
- Given the ample margin against requirements it was not prudent to expend resources to fully understand each local peak

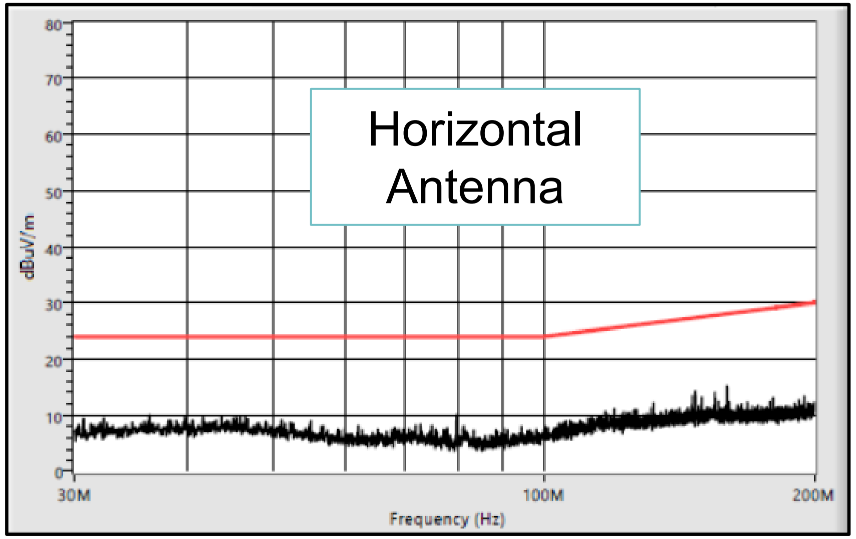
# RADIATED EMISSIONS

# CCOR-1 Wide Band Radiated Emission Examples (1 of 2)

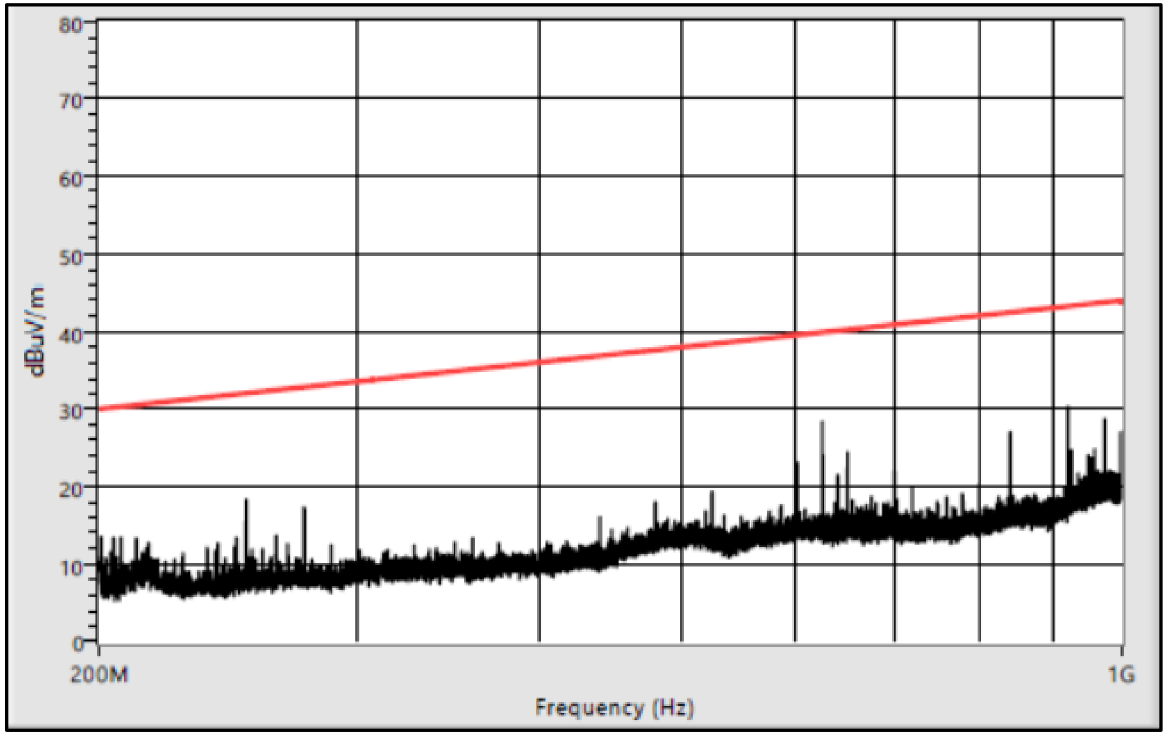


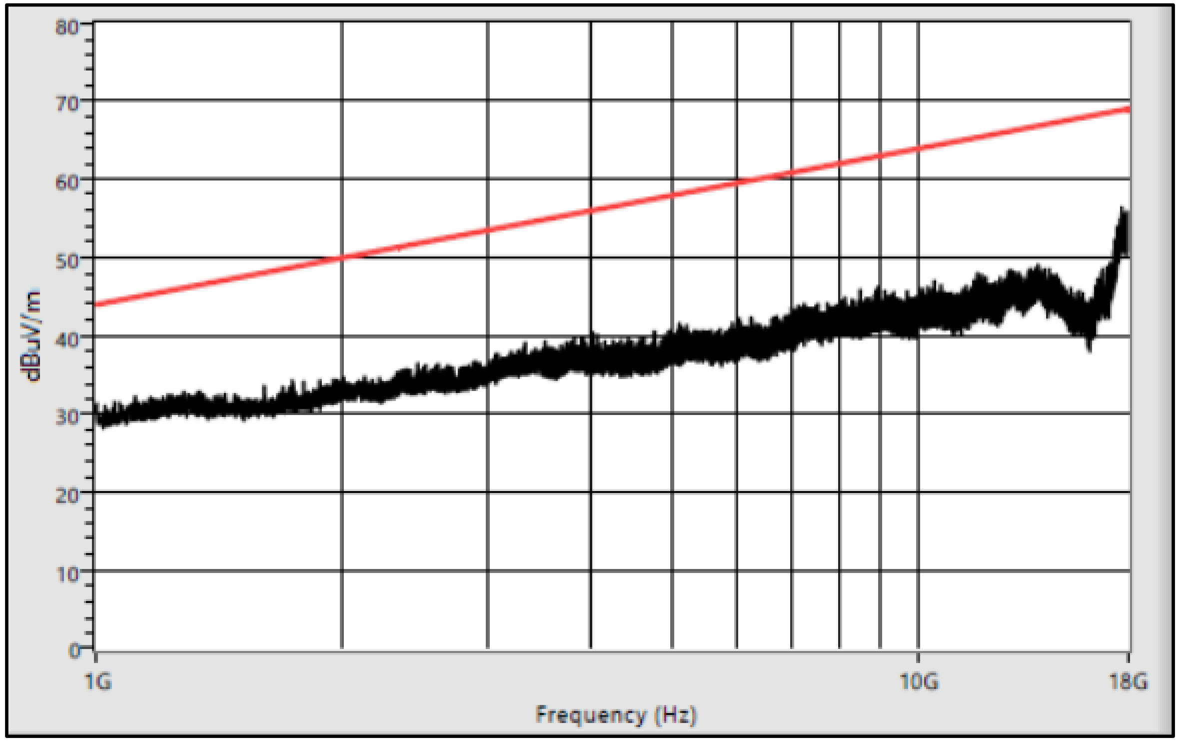




- Note: In the 30MHz to 200MHz there was a dramatic difference between the vertical and horizontal antenna positions
- The expected 80MHz oscillator noise is clearly seen in the vertical positon
- Antenna position was not notably relevant in most other cases



# CCOR-1 Wide Band Radiated Emission Examples (2 of 2)

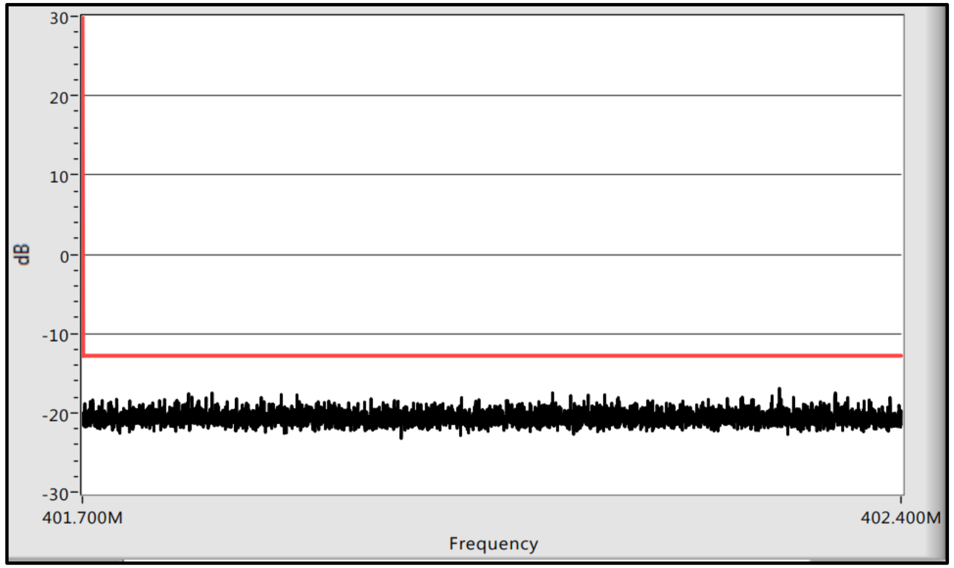


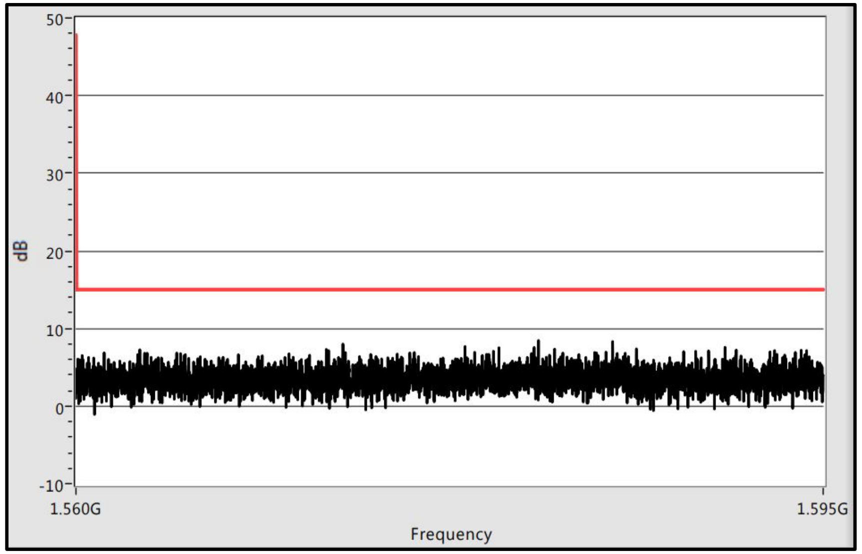




- These charts show the wide band radiated emissions of the CCOR instrument from 200MHz to 1GHz and 1GHz to 18GHz respectively

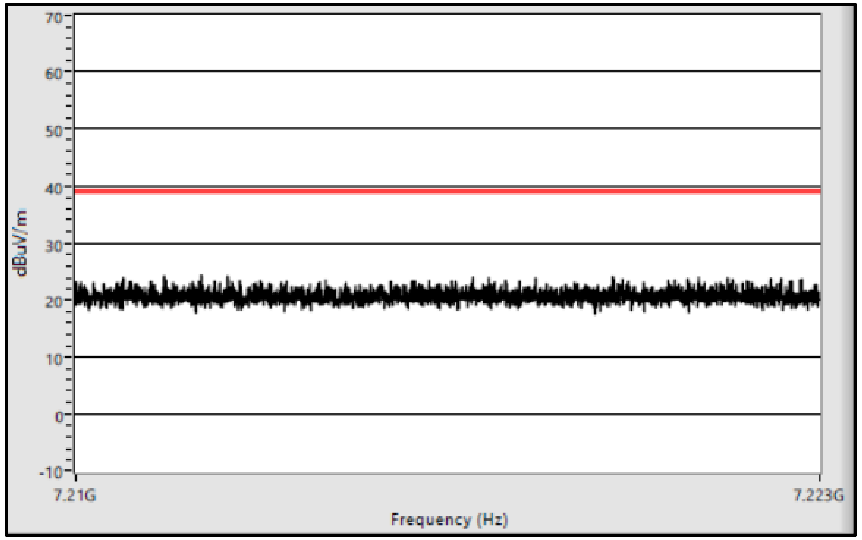
# NOTCH RADIATED EMISSIONS

# CCOR-1 Notch Radiated Emission Examples (1 of 2)

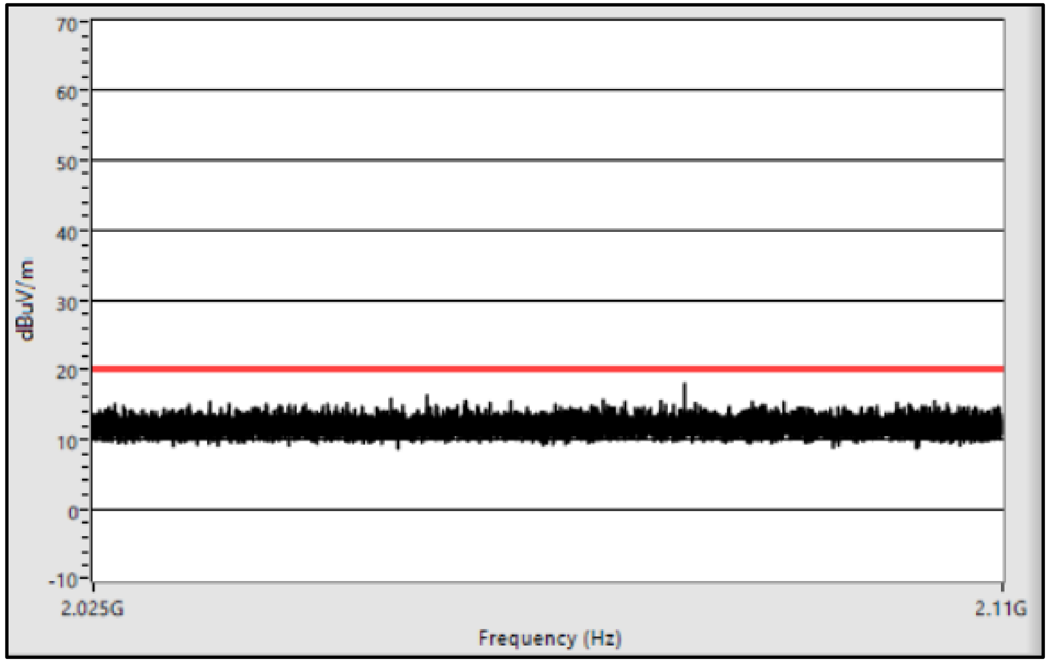


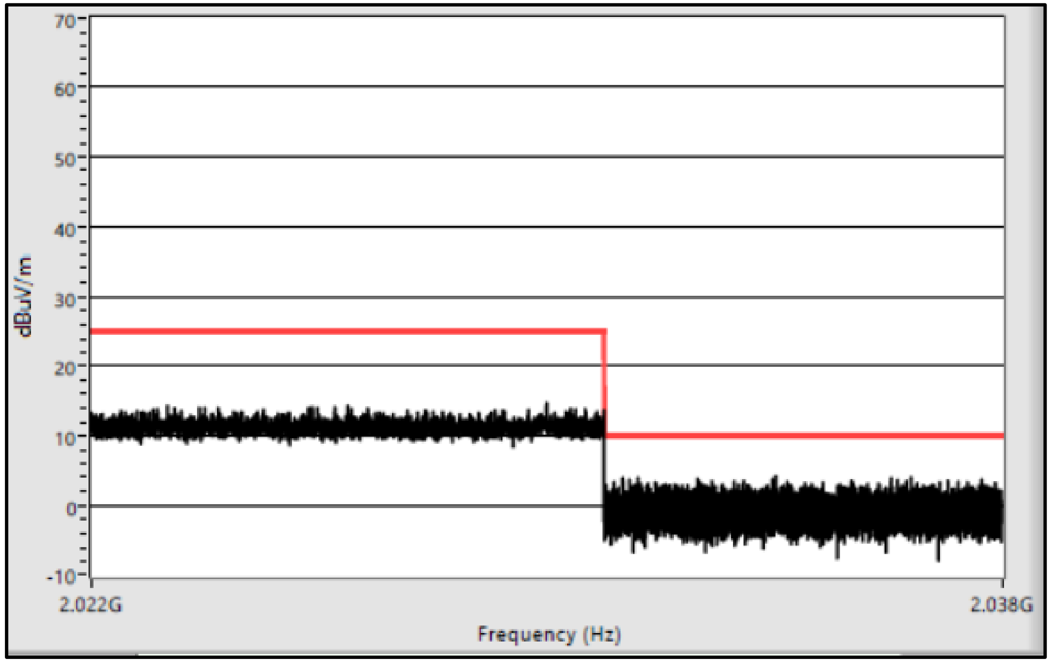




- Note: the measurement noise floor is adjusted based on the requirement for a particular notch
- Lower noise are more difficult to achieve and slower to test



# CCOR-1 Notch Radiated Emission Examples (2 of 2)




- CCOR Radiated Emissions: Operating Mode 2.02GHz to 2.11GHz

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# CCOR-2 Repeatability Lessons-Learned

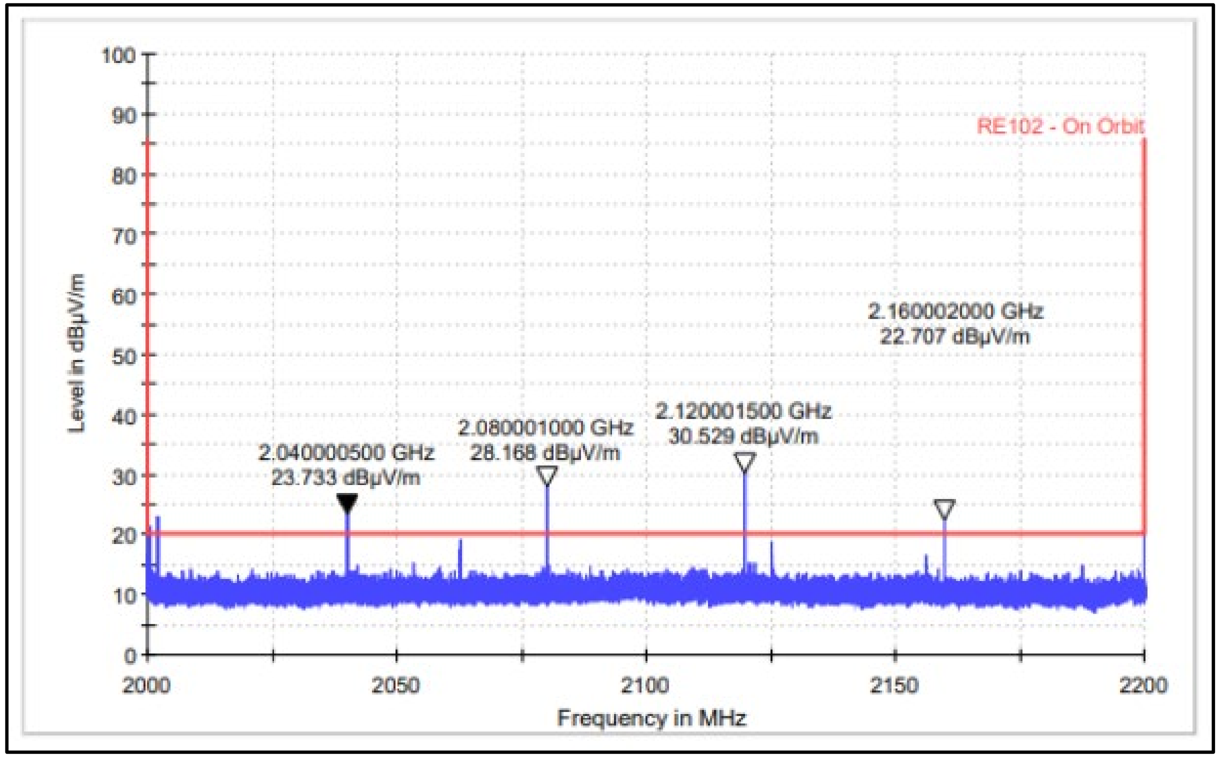
# CCOR-2 Repeatability Lessons-Learned (1 of 2)

- The results of CCOR-2 EMI tested demonstrated similar or improved performance in most aspects of the emission data.
- However, valuable lessons-learned came via the initial failure of a particular S-Band notch during radiated emission testing.
- While this exact notch had not been explicitly assessed in previous CCOR testing there was ample data in nearby/adjacent frequency bands that strongly suggested the design would pass.
- This gave engineers confidence that the exceedance could be overcome after further investigation.
- Engineers were able to determine that the exceedance or “leak” was specifically radiating from a single D-connector interface on the camera electronics.
- The level of exceedance was directly affected by this specific connector and would change significantly with even the most minor of adjustments.

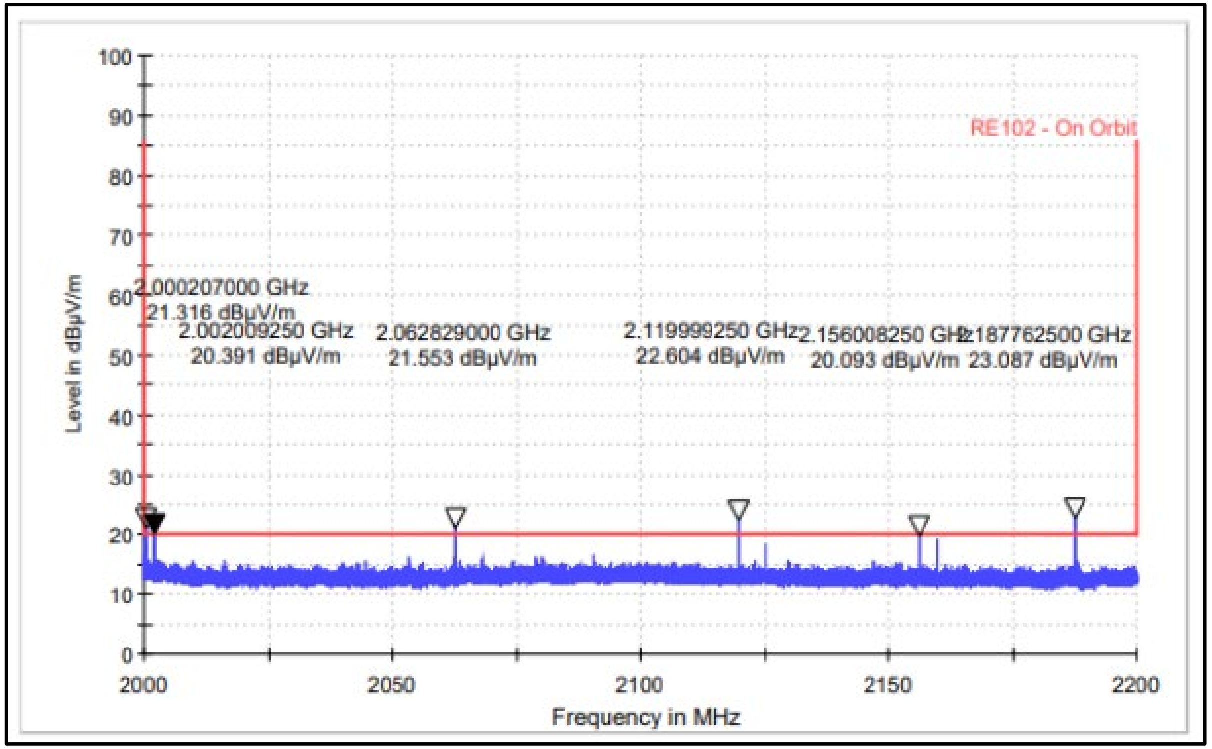
# CCOR-2 Repeatability Lessons-Learned (2 of 2)

- First engineers demonstrated that the emission could be eliminated by applying copper tape to the connector interface; a single layer of tape was found to be adequate.
- It was then demonstrated that the emission could be eliminated after a de-mate and careful re-mate of this connector without requiring any copper taping of the interface.
- Due to resource and schedule constraints no further trouble shooting or testing occurred..
- While the taping was shown to be unnecessary to meet emissions; including the taping did not have any negative impact on the thermal design, mass constraints, or create any contamination concerns.
- It should be noted that the initial exceedance was observed after an experienced flight technician and QA engineer carefully mating and inspected the interface.
    - This was not a case of incidental human error such as an improperly seated connector, lack of thread engagement, or incorrect torque

# CCOR-2 Notch Initial Failure

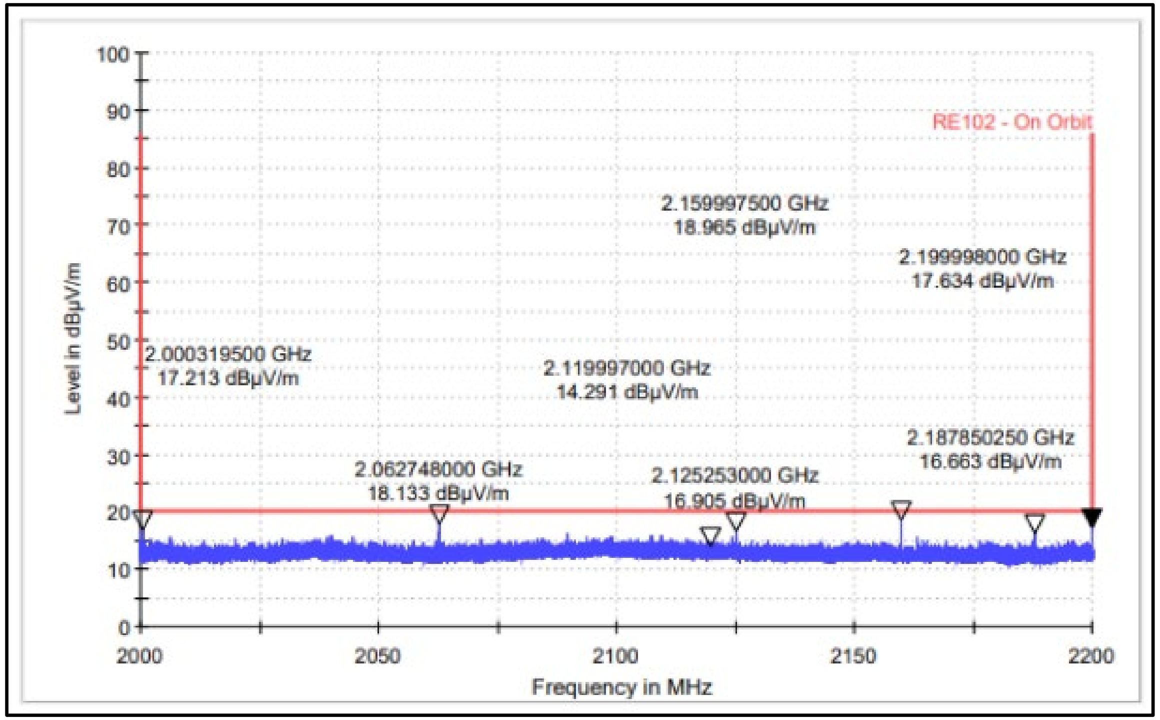



Vertical Imaging Mode

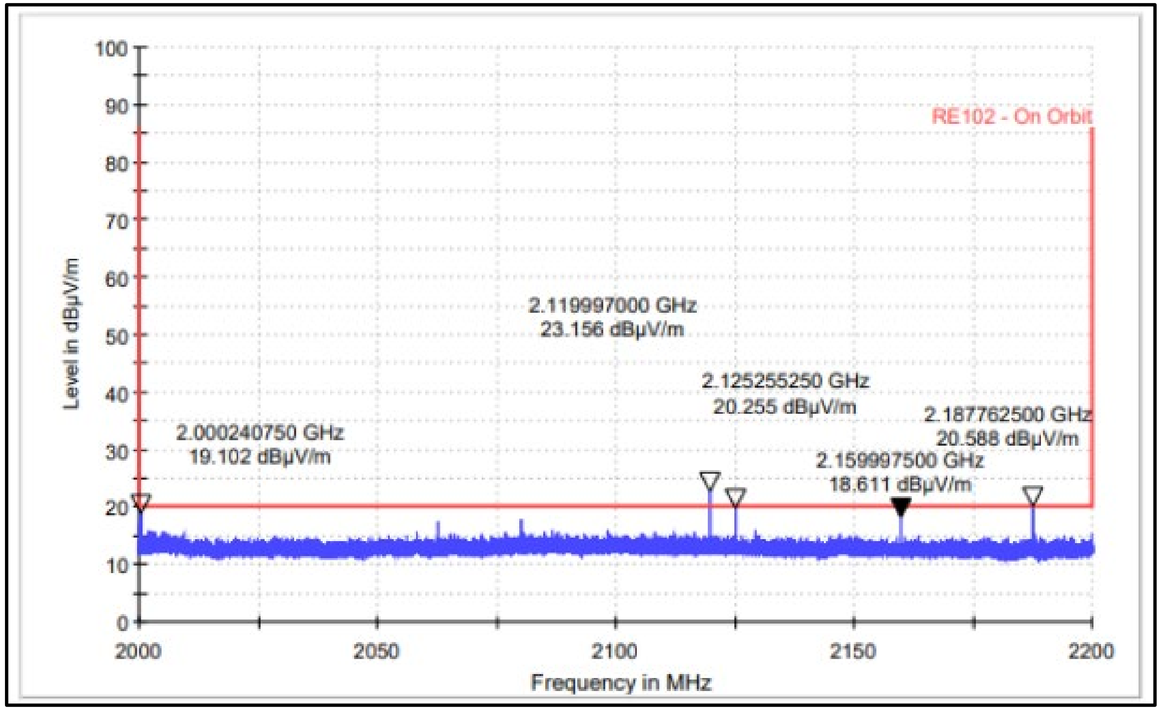



Horizontal Imaging Mode

# CCOR-2 Notch Initial Taping Resolution



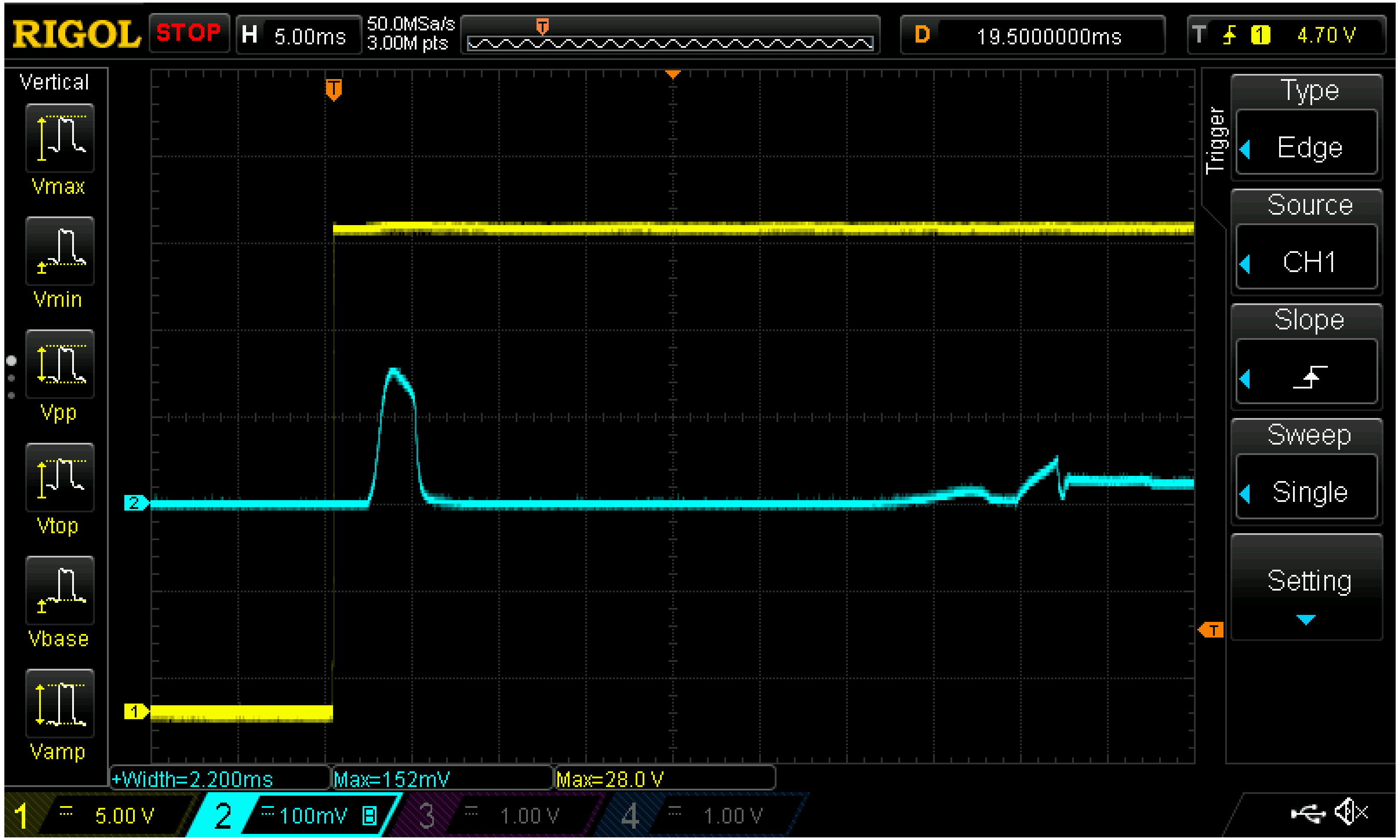

Vertical Imaging Mode



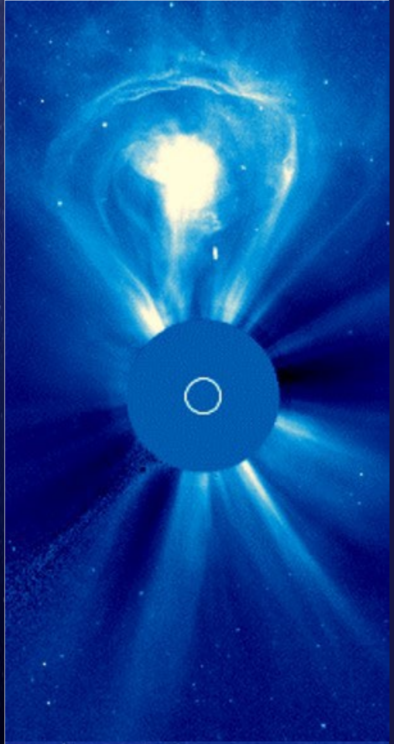

Horizontal Imaging Mode

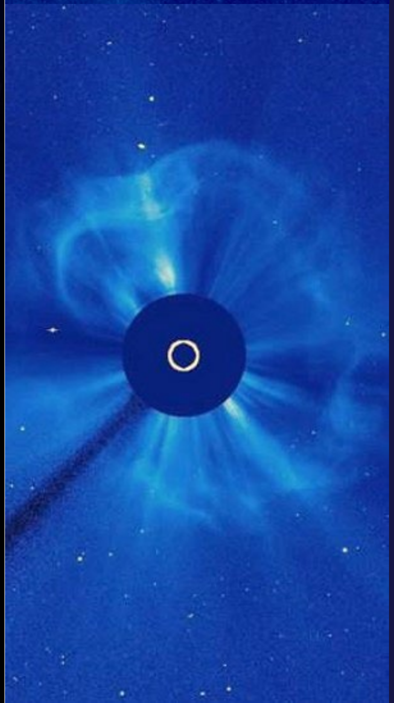
# INRUSH

# 28VDC Bus Inrush Results (Power-On)




- Yellow Trace: 28VDC
- Blue Trace: CCOR-2 Current (1A/1V)



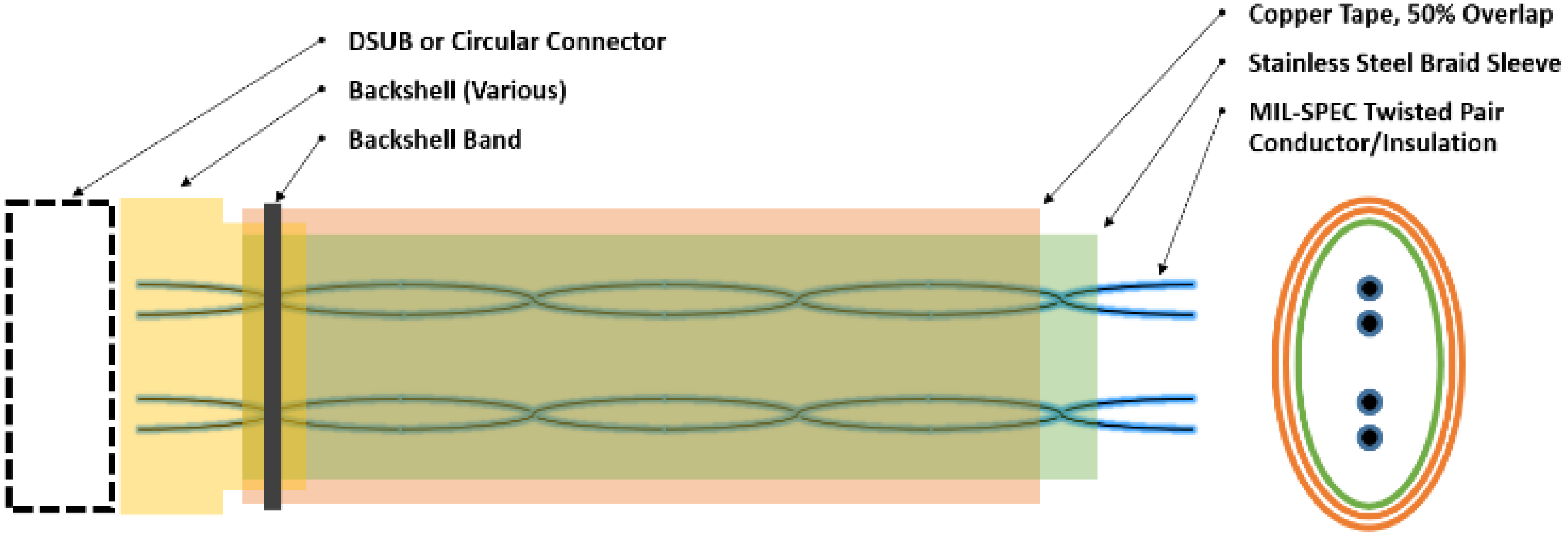


# HARNESS DESIGN

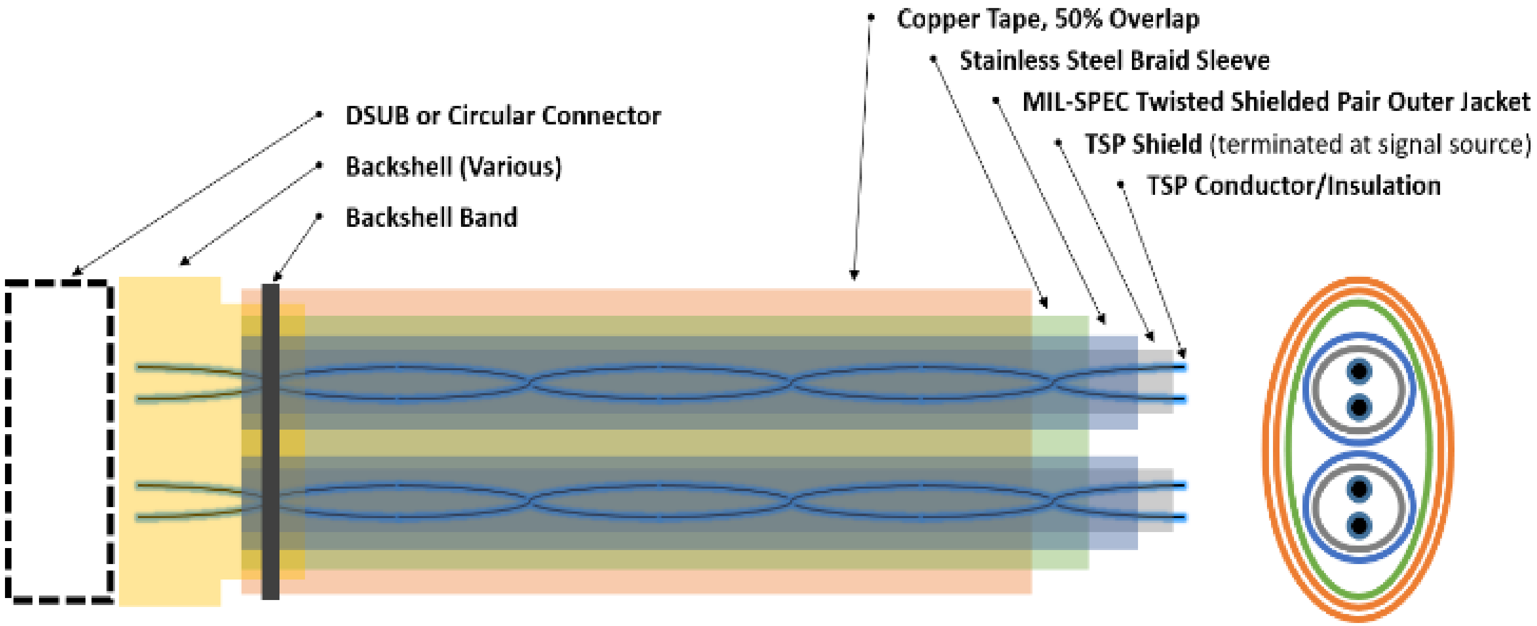
# Harness Design Overview

- Unshielded-twisted pairs (exception for digital signals, TSP)
- Armorlite braid (nickel-clad stainless steel braid)
- 50% overlap copper tape
    - EM testing met emission requirements without copper tape
    - Copper tape provides extra shielding regardless and protects the instrument from some deep-dielectric charging effects
- EMI gaskets used on connector interfaces to electronics boxes

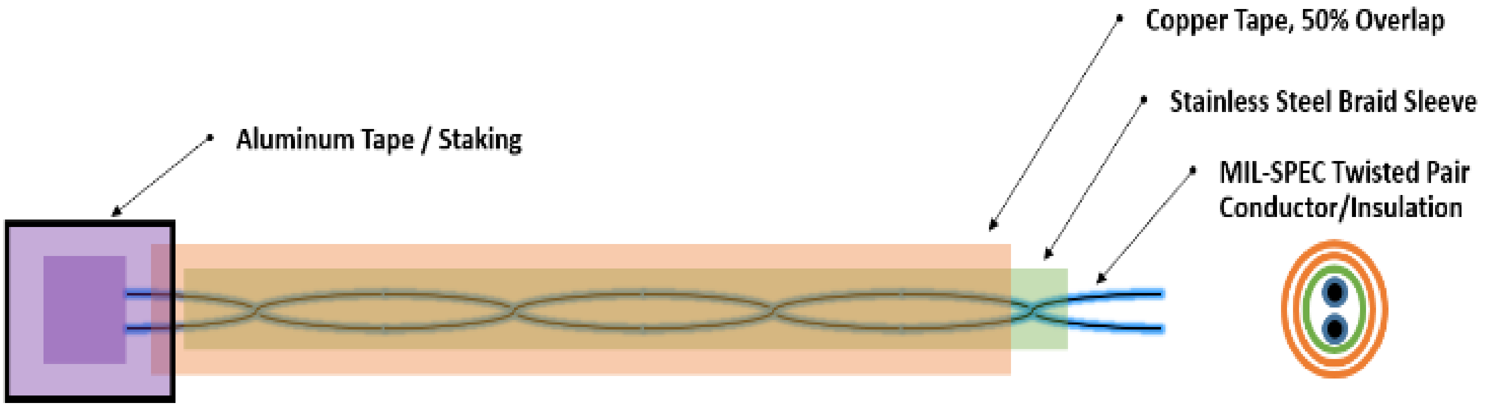
# Harness Design: Power



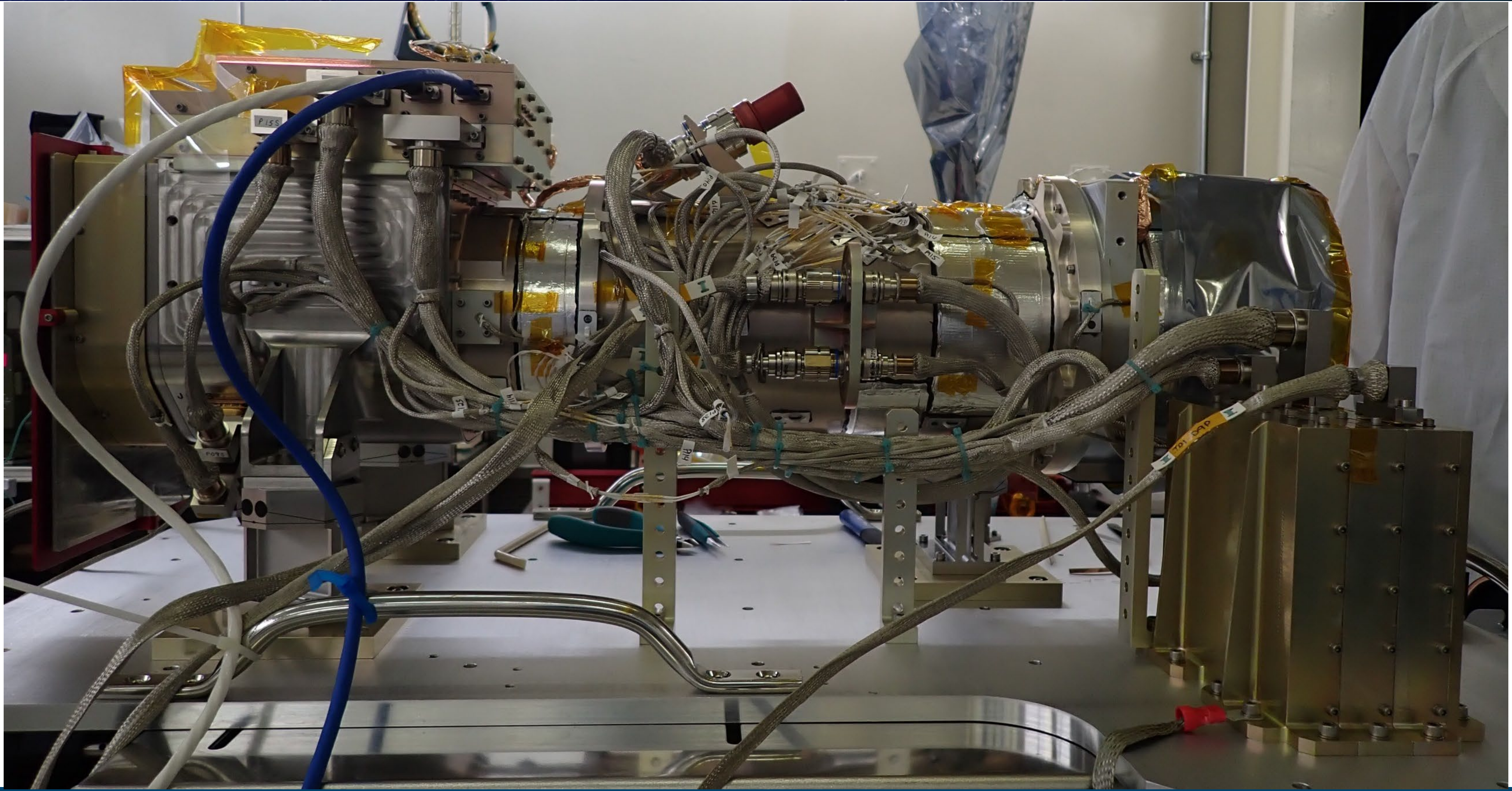
# Harness Design:  Digital Signals



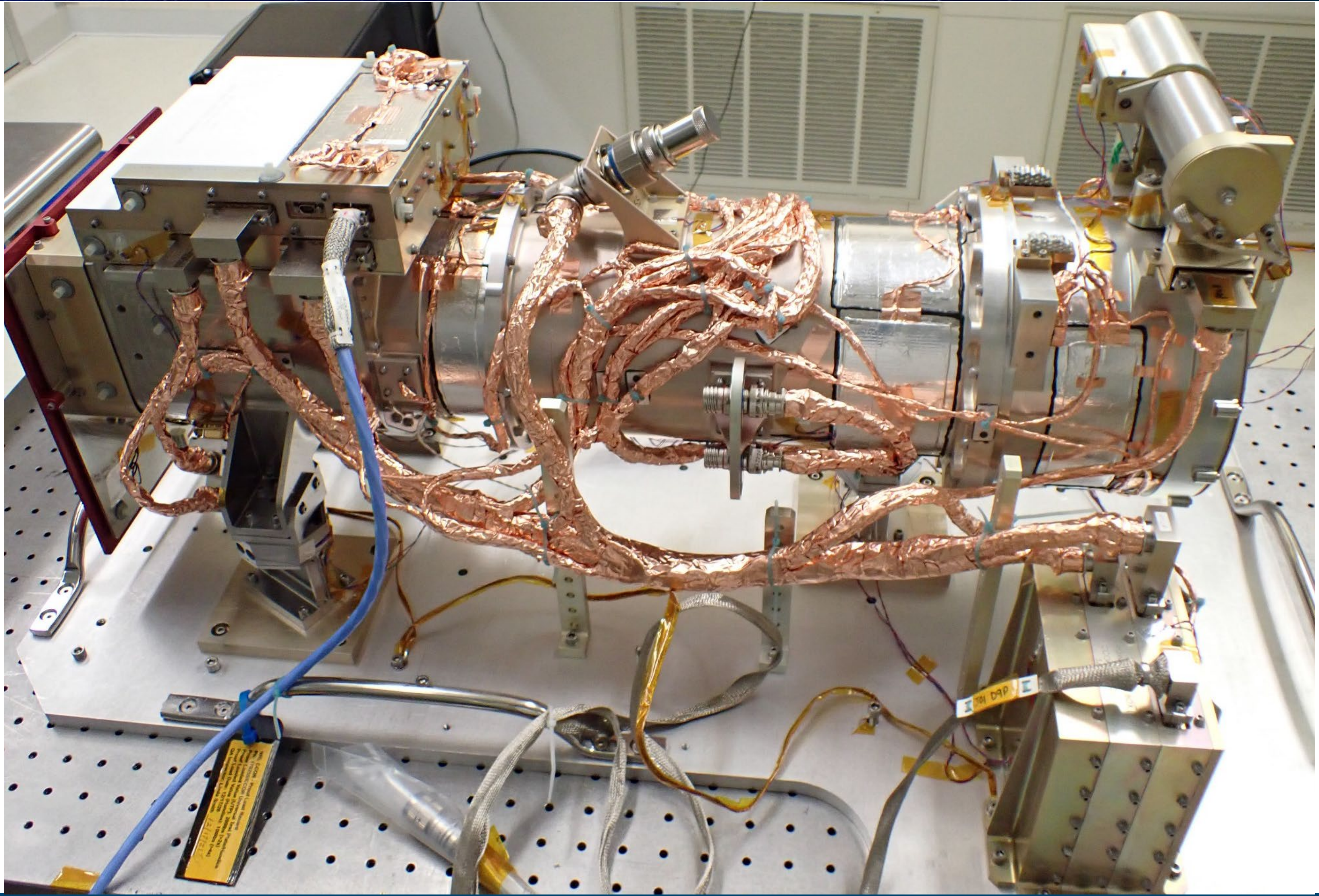
# Harness Design: Instrumentation & Analog



# Harness Design: Photos



# Harness Design: Photos



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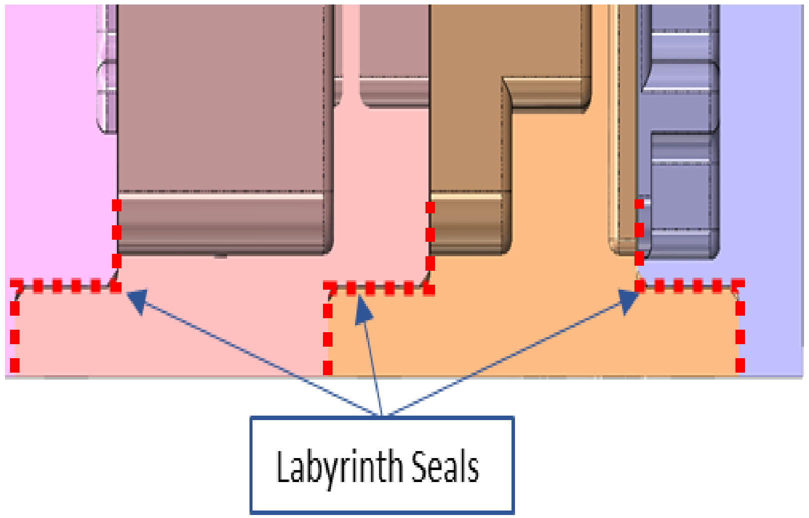
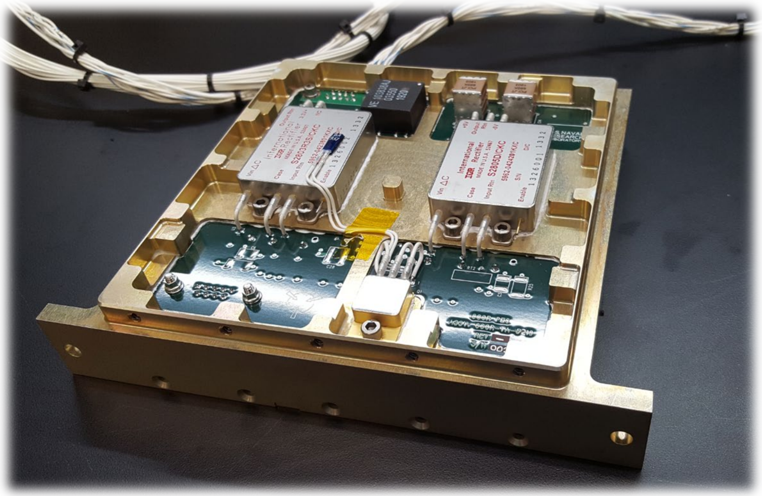
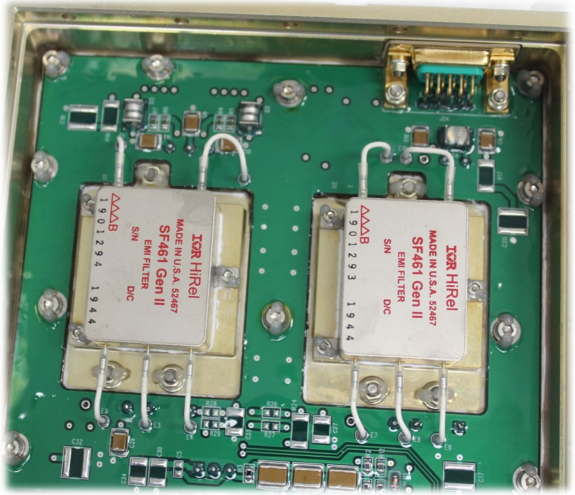
# MECHANICAL DESIGN

# Mechanical EMI Design

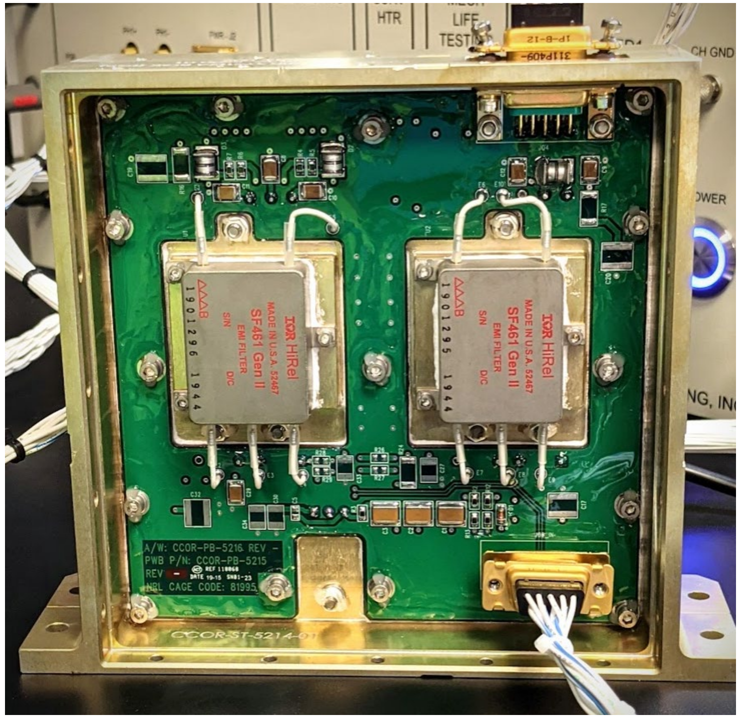


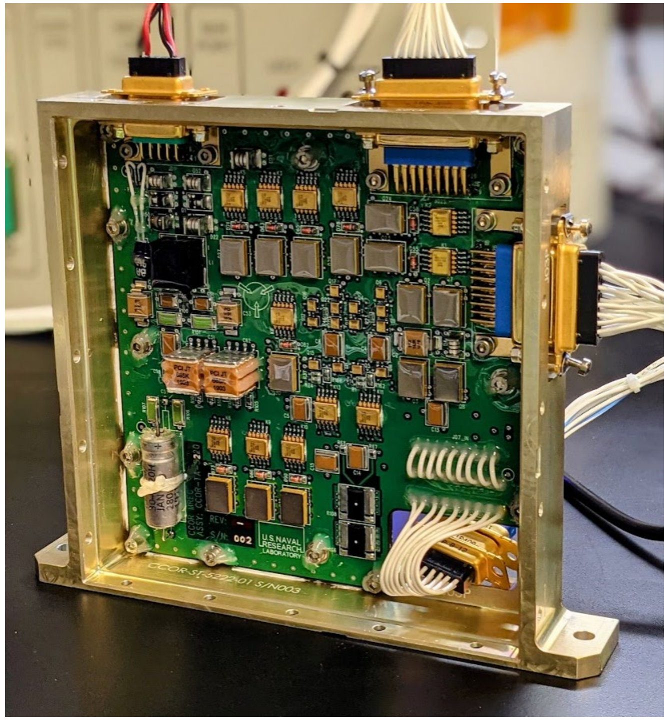



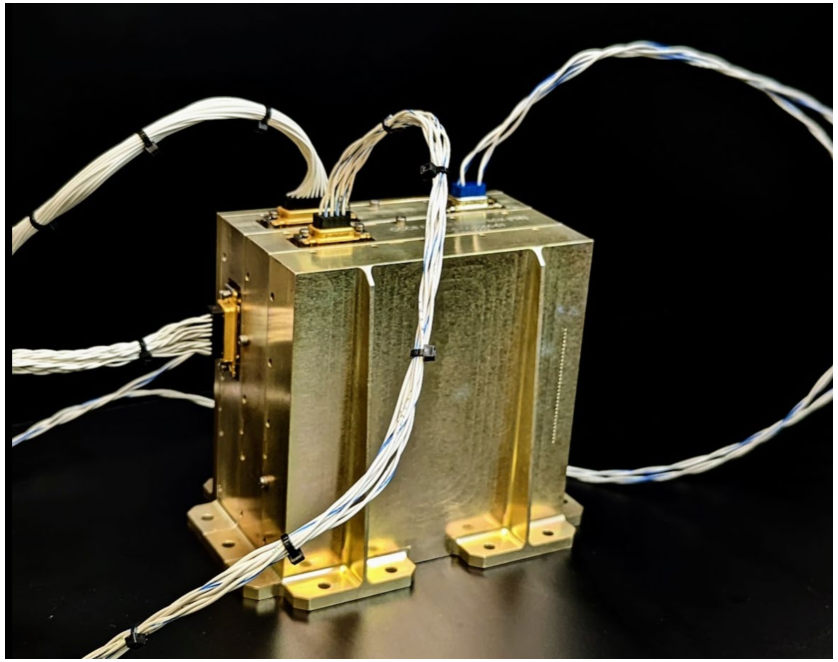


- Mechanical designs utilized what is commonly known as “labyrinth seal”; metal interfaces which overlap on multiple surfaces when joining pieces of a structure.
- This helps ensure a tighter fit from the perspective of EMI emissions.
- This figure shows three sequential labyrinth seals used in the CCOR electronics enclosure.
- Conductive gasket material was also used on several mechanical interfaces including electrical connectors.
- Mechanical designers accounted for the compressed thickness of the gasket materials to ensure a precise close out of those interfaces.

# PSB Mechanical Assembly

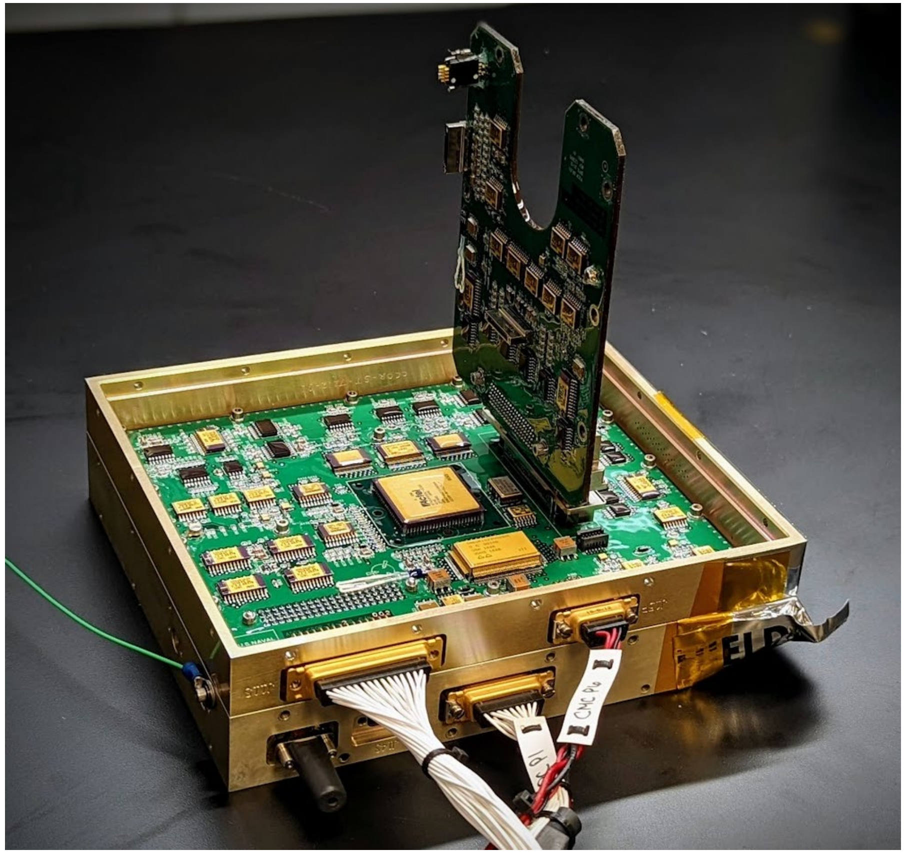


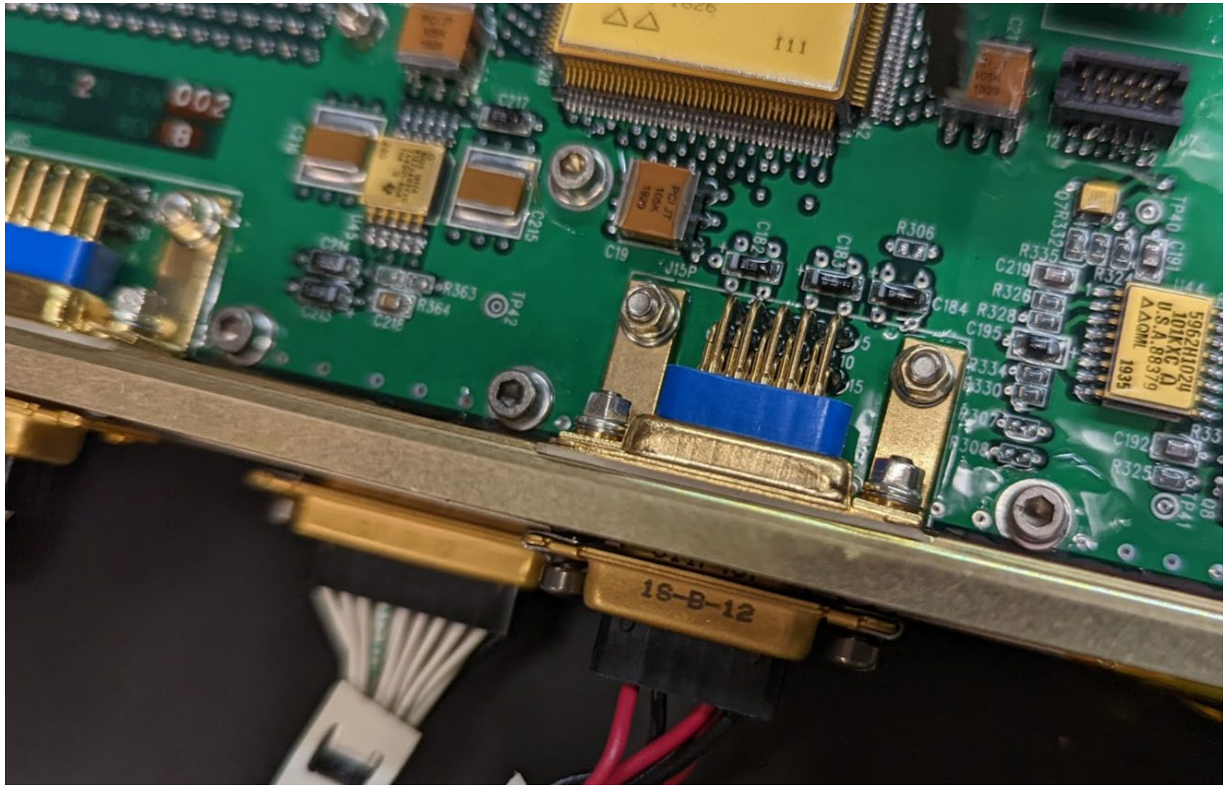





- The two card slices with labyrinth style seals that form the PSB

# ICB Mechanical Assembly






- The ICB with a close up of the connector gasket

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# SUMMARY & CONCLUSIONS

# Summary & Conclusions

- CCOR was able to meet unusually difficult EMI requirements:
    - Supplemented high-rel COTS power converters with additional filtering
    - Utilized fairly common best practices to ensure mechanical designs created tight faraday cages
    - Armorlite covered harnesses with copper taping and EMI gaskets on connector interfaces
    - Tested flight-like EM emissions early to buy-down risk
- Emissions is shared as reference for future programs
- Similar results should be achievable by following similar design strategies and practices
- CCOR-2 had an initial notch failure that was easily addressed with copper taping
    - This demonstrated that minor variations in manufacturing can impact performance

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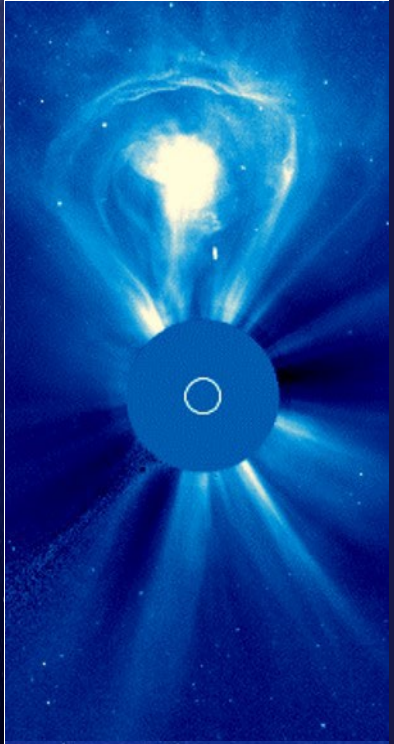

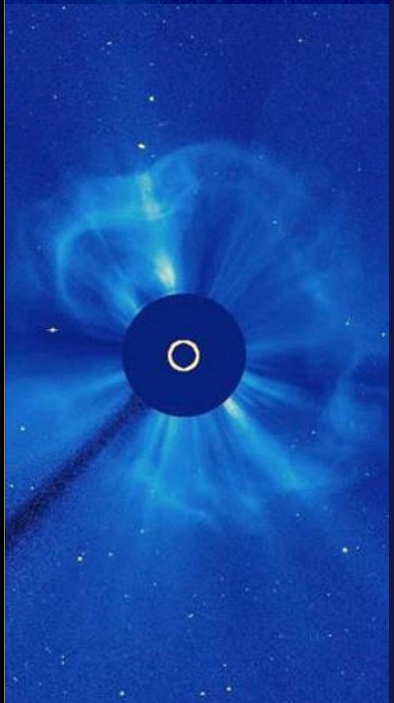

# QUESTIONS?