Proper Flow-down and Tailoring of MIL-STD 461G EMC Requirements for the Europa Clipper Mission

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Jet Propulsion Laboratory, California Institute of Technology

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July 22, 2019

Exploring Europa's Habitability: Ingredients for Life

Water:

- Probable saltwater ocean, implied by surface geology and magnetic field
- Possible lakes within the ice shell, produced by local melting

Chemistry:

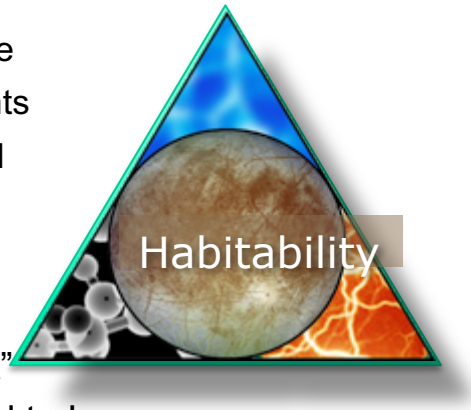
- Ocean in direct contact with mantle rock, promoting chemical leaching
- Dark red surface materials contain salts, probably from the ocean

Energy:

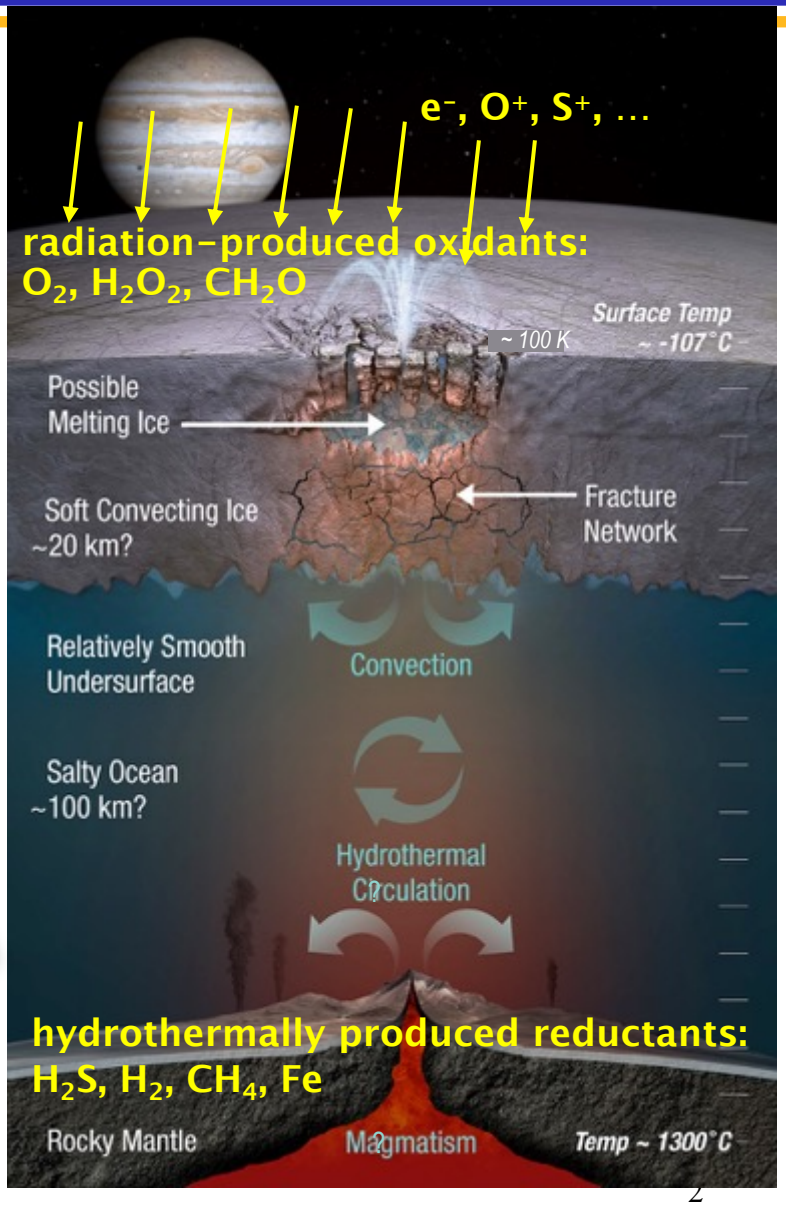
- Chemical energy might sustain life
- Surface irradiation creates oxidants
- Mantle rock-water reactions could create reductants (hydrothermal or serpentinization)

Activity:

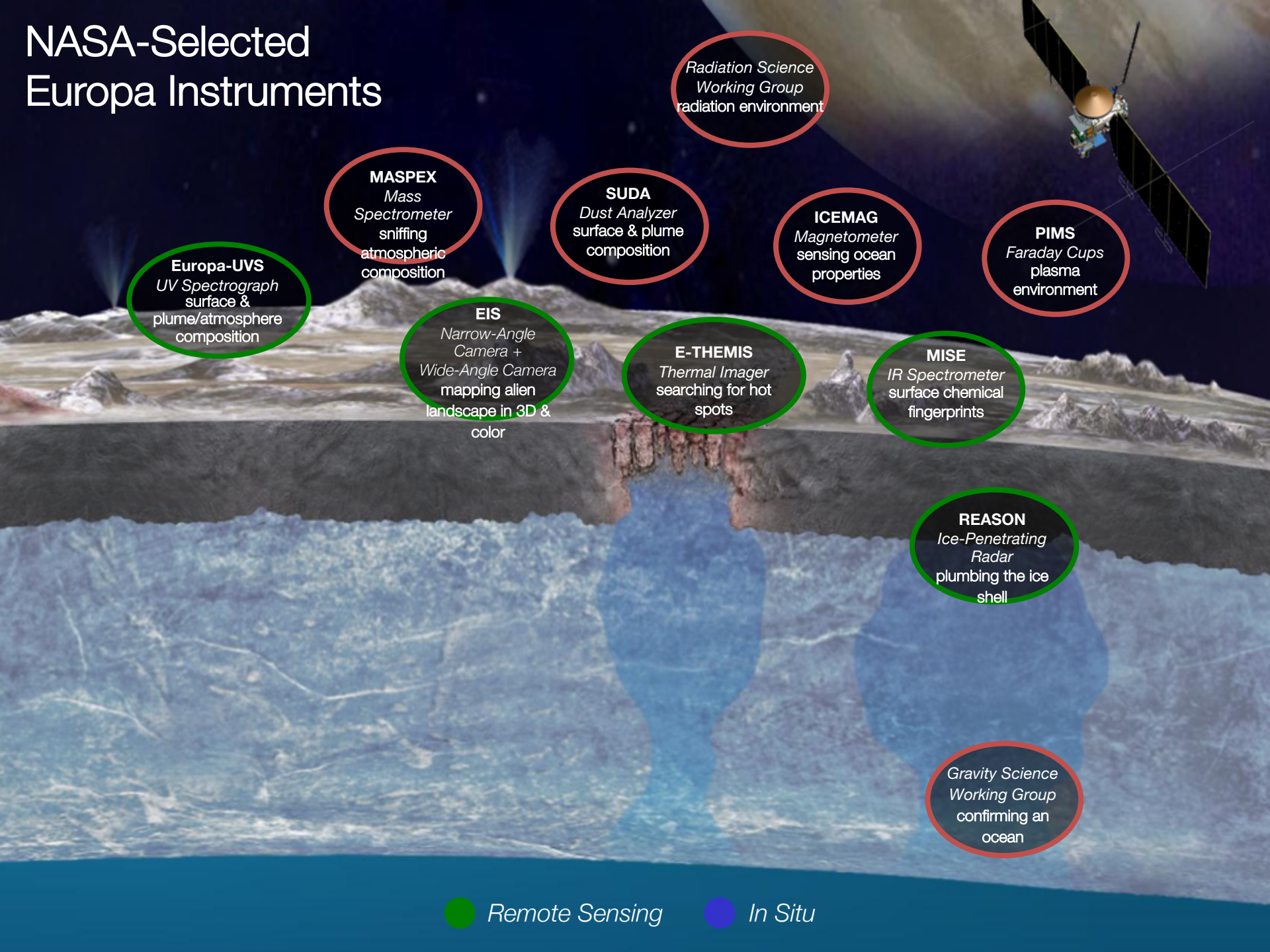
- Geological activity "stirs the pot"
- Activity could be cyclical, as tied to Io



Europa Flyby Mission will test key habitability hypotheses

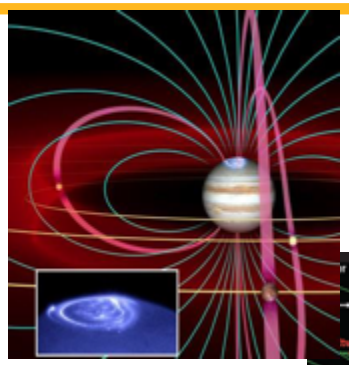


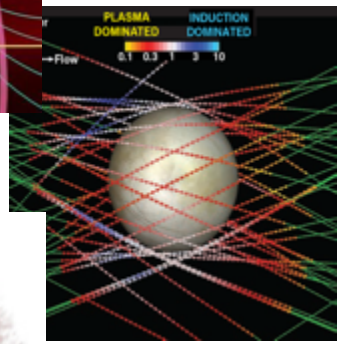
NASA-Selected Europa Instruments

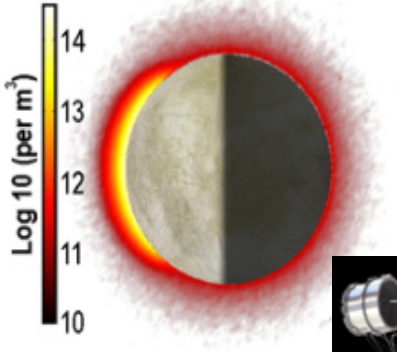


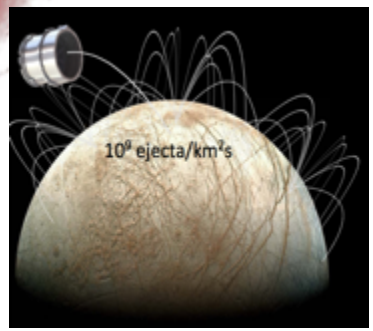
Europa *In Situ* Investigations

- **Interior Characterization of Europa using Magnetometry (ICEMAG) – PI Dr. Carol Raymond, JPL**
  - Magnetometer to measure the magnetic field near Europa and infer the location, thickness and salinity of Europa's subsurface ocean using multi-frequency electromagnetic sounding.
- **Plasma Instrument for Magnetic Sounding (PIMS) – PI Dr. Joseph Westlake, APL, Laurel, Maryland**
  - In conjunction with a magnetometer, is key to determining Europa's ice shell thickness, ocean depth, and salinity by correcting the magnetic induction signal for plasma currents around Europa.
- **MAss SPectrometer for Planetary EXploration/Europa (MASPEX) – PI Dr. Jack (Hunter) Waite, SwRI, San Antonio**
  - To determine the composition of the surface and subsurface ocean by measuring Europa's extremely tenuous atmosphere and any surface material ejected into space.
- **SUrface Dust Mass Analyzer (SUDA) – PI Dr. Sascha Kempf, University of Colorado, Boulder**
  - To measure the composition of small, solid particles ejected from Europa, providing the opportunity to directly sample the surface and potential plumes on low-altitude flybys.









Europa Remote Sensing Investigations

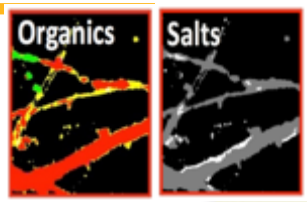
- **Mapping Imaging Spectrometer for Europa (MISE) – PI Dr. Diana Blaney, JPL**
  - **Probe the composition of Europa, identifying and mapping the distributions of organics, salts, acid hydrates, water ice phases, and other materials to determine the habitability of Europa's ocean.**

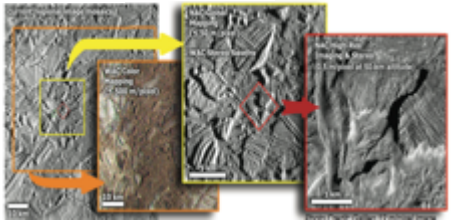
- **Europa Imaging System (EIS) – PI Dr. Elizabeth Turtle, APL**
  - **Wide and narrow angle cameras to map most of Europa at better than 100 m resolution, and to provide images of areas of Europa's surface at up to 100 times higher resolution.**

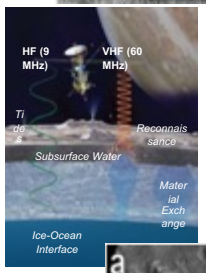
- **Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON) – PI Dr. Donald Blankenship, University of Texas, Austin**
  - **Characterize and sound Europa's icy crust from the near-surface to the ocean, revealing the hidden structure of Europa's ice shell and potential water within.**

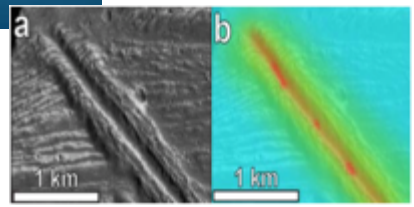
- **Europa Thermal Emission Imaging System (E-THEMIS) – PI Dr. Philip Christensen, Arizona State University, Tempe**
  - **Provide high spatial resolution, multi-spectral thermal imaging of Europa to help detect active sites, such as potential vents erupting plumes of water into space.**

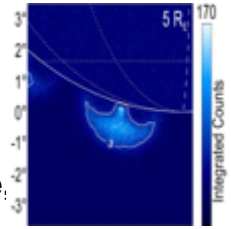
- **Ultraviolet Spectrograph/Europa (UVS) – PI Dr. Kurt Retherford, SwRI, San Antonio**
  - **Detect the likely presence of water plumes erupting from Europa's surface, including small plumes, and to provide valuable data about the composition and dynamics of Europa's rarefied atmosphere.**



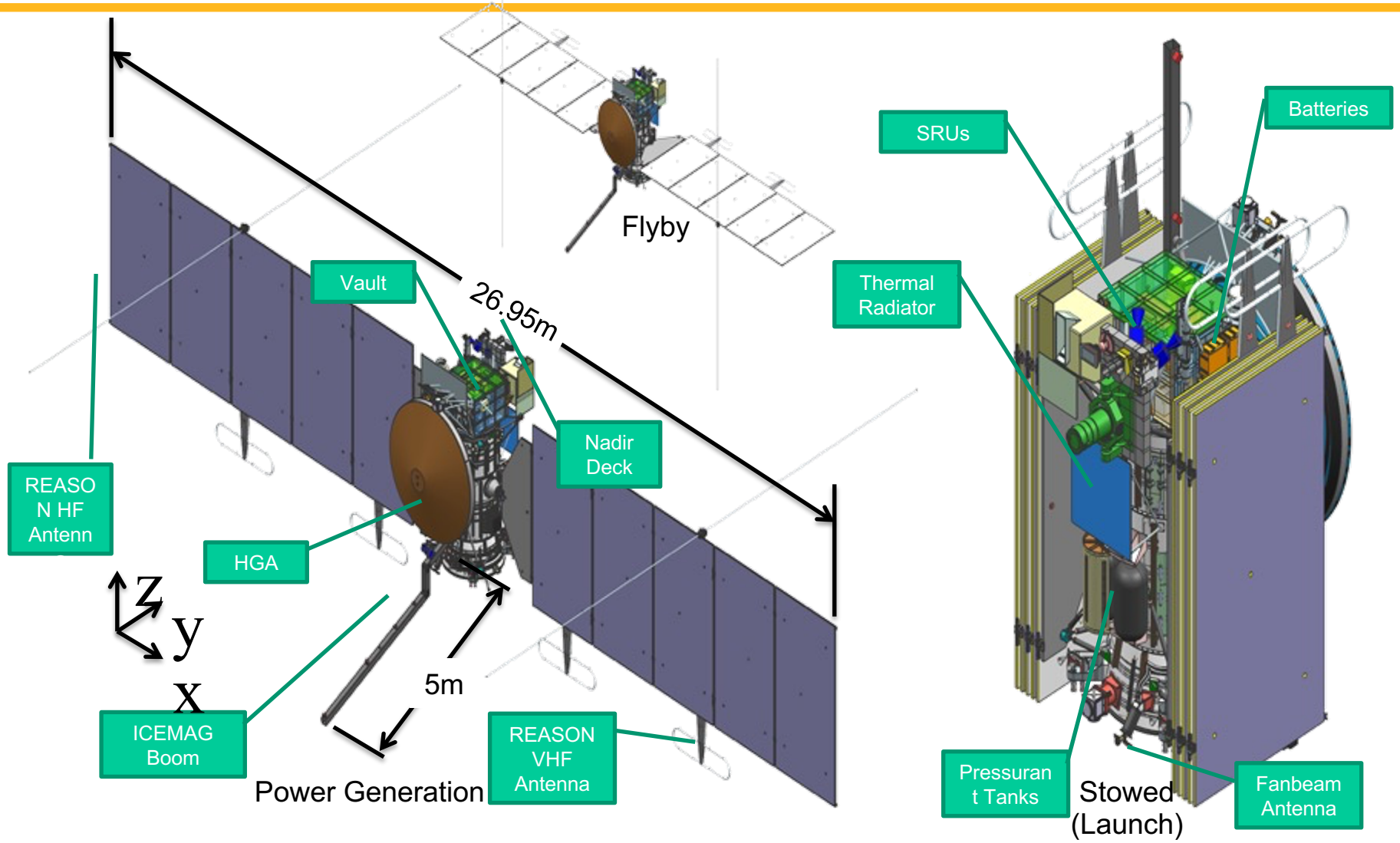




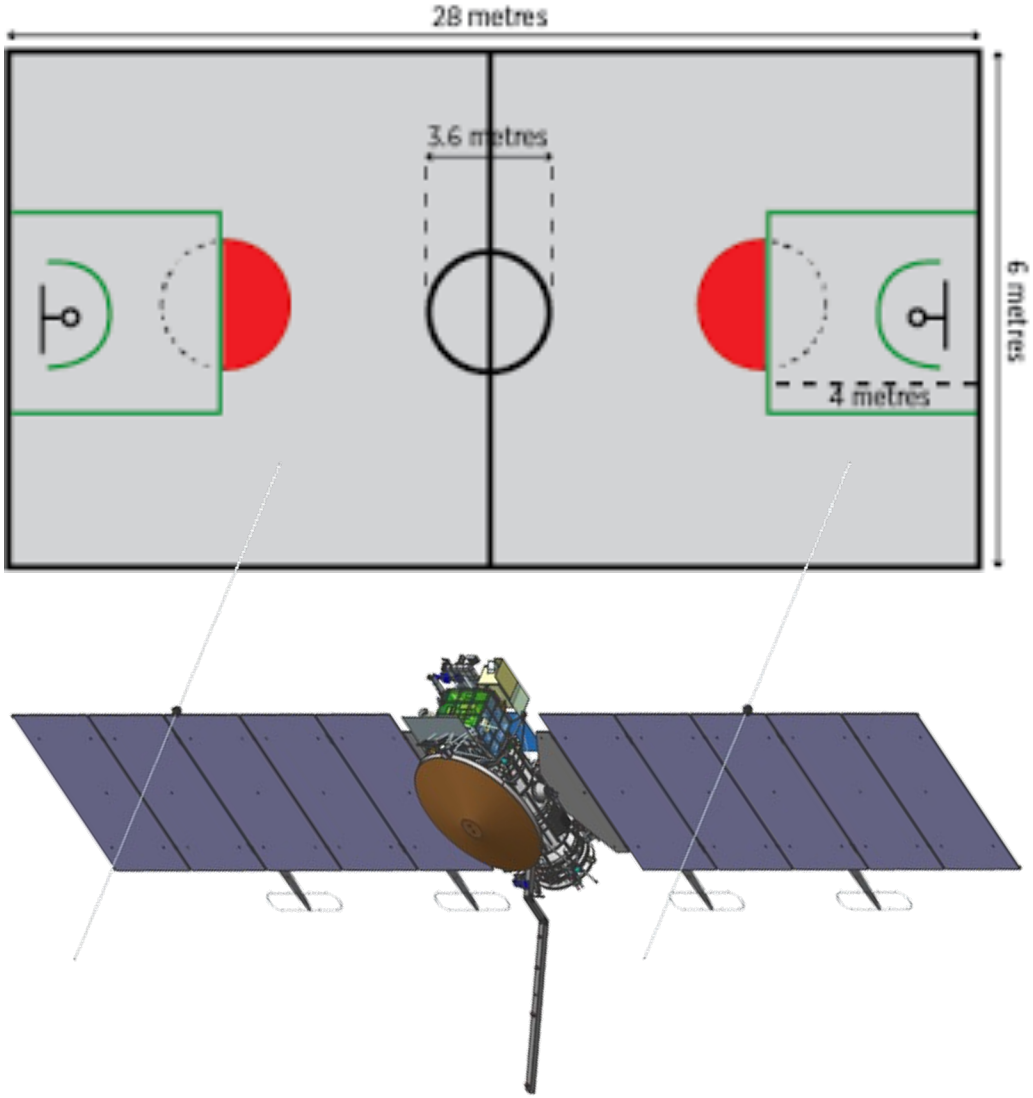




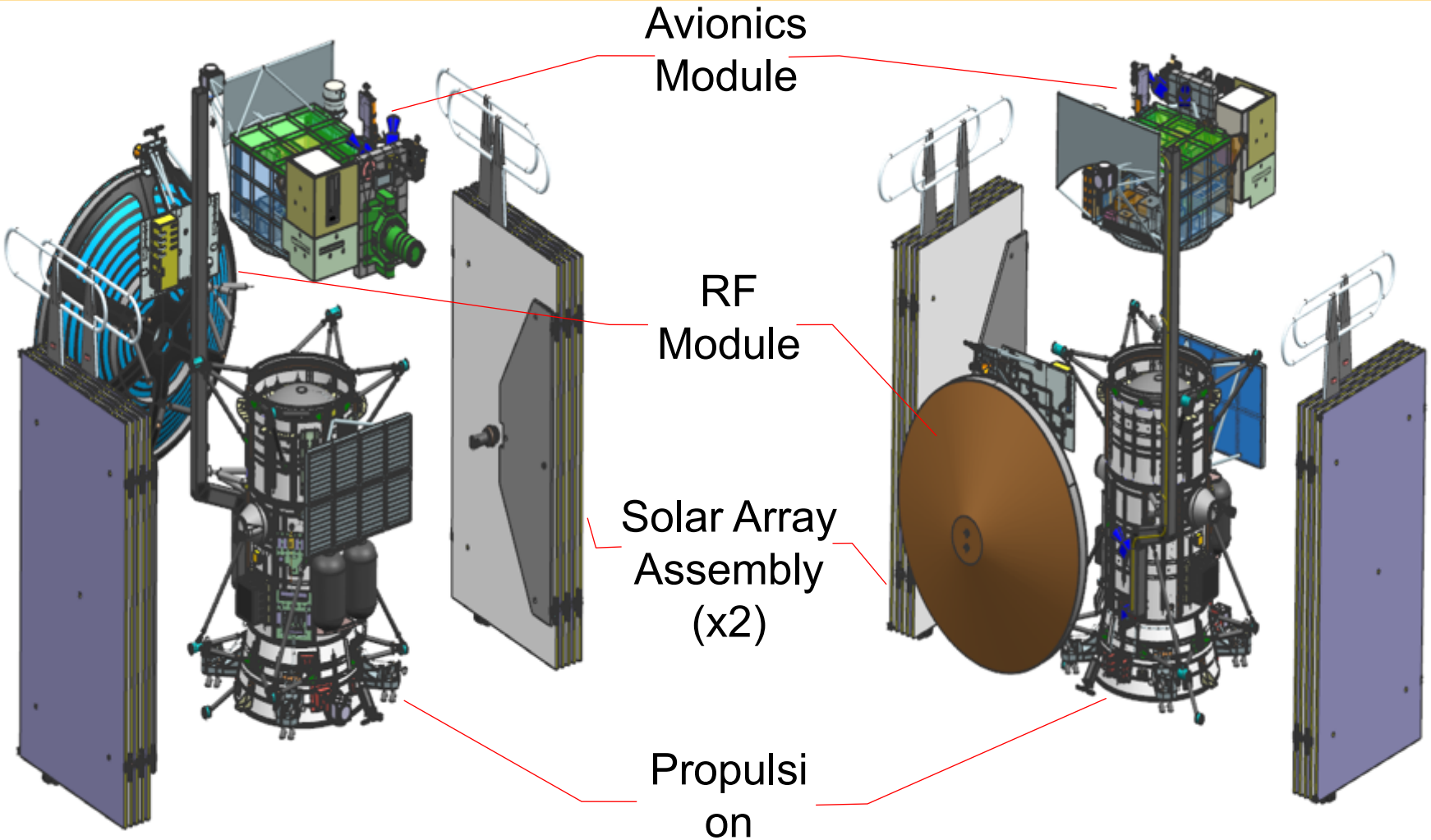
Europa Configuration



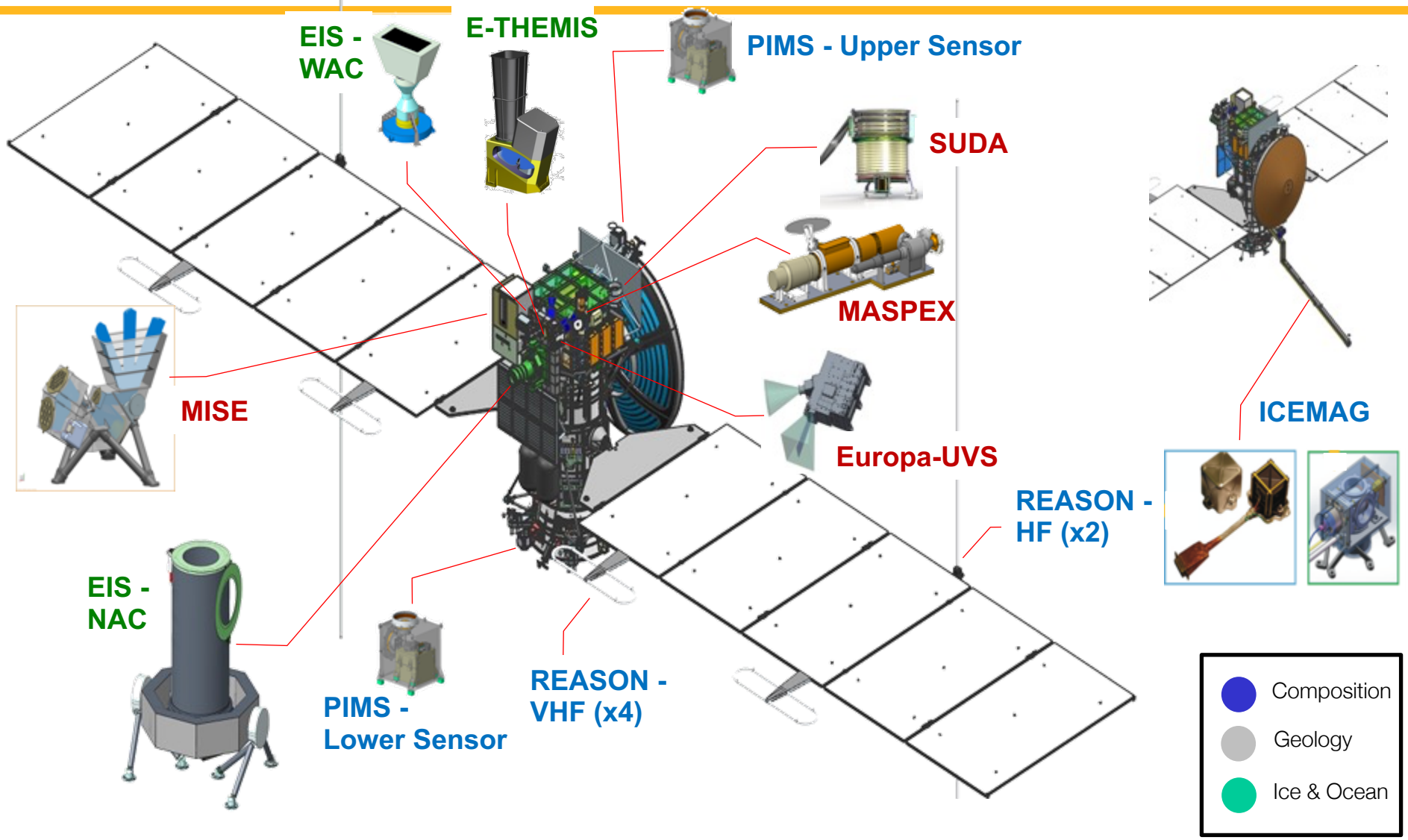
Europa Configuration



Flight System Exploded View



Europa Clipper Science Payload



Europa Clipper Mission EMC Tests

Test Method	Test Description	Assembly/ Subsystem/ Instrument	Flight System
CE101 (Tailored 461F)*	Conducted Emissions, Power Leads, 30 Hz to 50 MHz	Test	---
CECM	Conducted Emissions, Common Mode, 30 Hz to 200 MHz	Test	---
CE106 (Tailored 461F)	Conducted Emissions, Antenna Terminals	Test	---
CE07 (Tailored 461C)*	Conducted Emissions, Power Transients, Time Domain	Test	---
CS101 (Tailored 461F)	Conducted Susceptibility, Power Leads, 30 Hz to 150 kHz	Test	---
CS104 (Tailored 461F)	Conducted Susceptibility, Rejection of Undesired Signals	Test	---
CS106 (Tailored 461F)	Conducted Susceptibility, Power Line Transients - Spikes (CS106)	Test	---
CS114 (461F)	Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 200 MHz	Test	---
CS114 (461F)	Conducted Susceptibility, Power Leads, Differential Mode, 10 kHz to 200 MHz	Test	---
RE101 (461F)	Radiated Emissions, AC Magnetic Field, 30 Hz to 100 kHz	Test	---
RE102 (Tailored 461F)	Radiated Emissions, AC Magnetic Field, 30 Hz to 18 GHz	Test	Test

Europa Clipper Mission EMC Tests

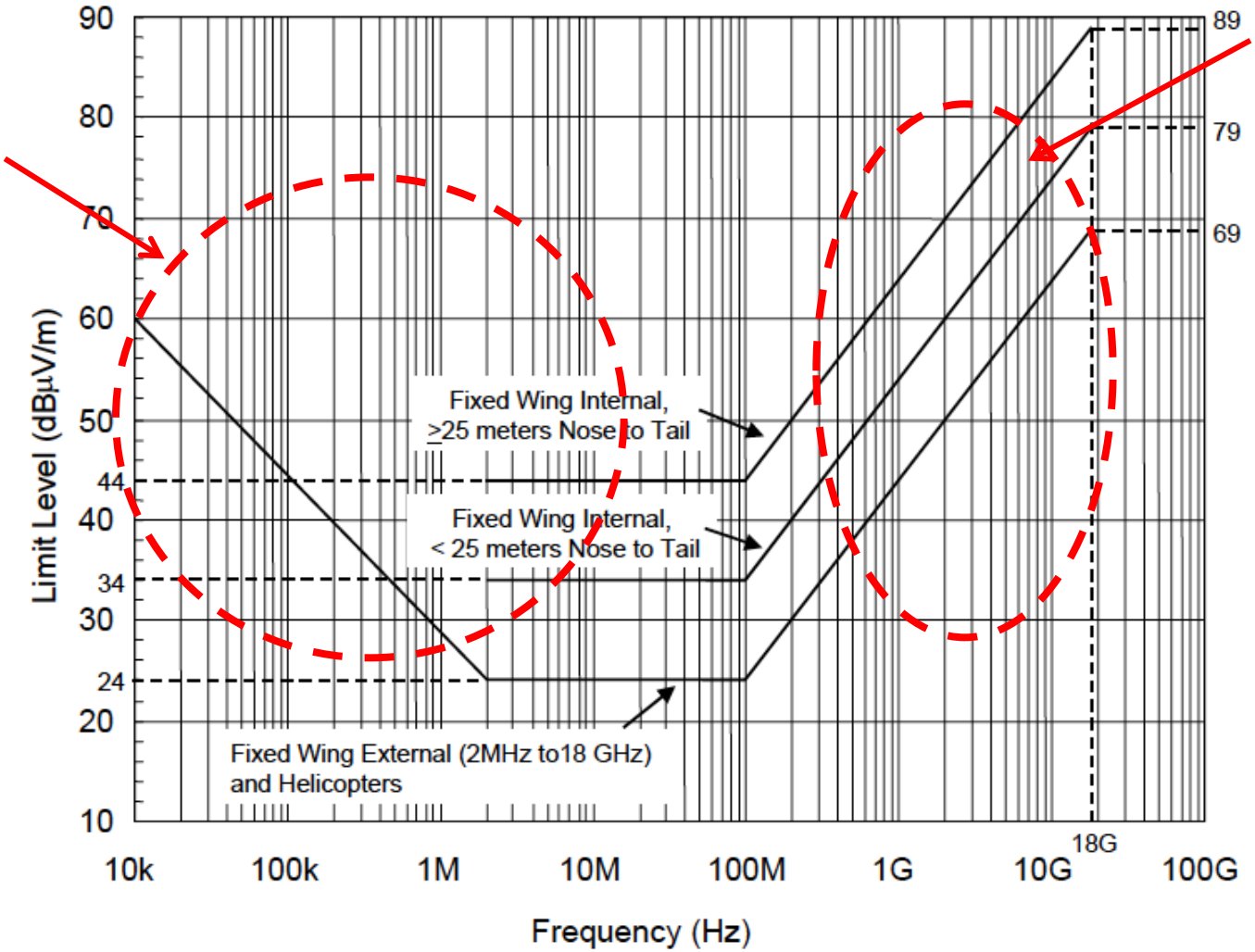
Test Method	Test Description	Assembly/ Subsystem/ Instrument	Flight System
RS101 (461F)	Radiated Susceptibility, AC Magnetic Field, 30 Hz to 100 kHz	Test	---
RS103 (461F)	Radiated Susceptibility, Electric Field, 14 kHz to 18 GHz	Test	Test
Magnetics	DC Magnetic Field Emissions	Test	---
Magnetic Moment	DC Magnetic Field Emissions /Moment	Test/ Analysis	Test/ Analysis
Power Transients	In-Rush Current	Test	---
Power Transients	Turn-off Transients	Test	---
Operational Transients	Normal Transients	Test	---
Operational Transients	Abnormal Transients	Test	---
Power Transients	Power Interrupt	Test	---
Ground Fault	Power Ground Fault Test	Test	---
Lightning	Lightning Transients	Test/ Analysis	---
Bonding and Grounding	EMI Bonding Resistance Measurement	Test/ Inspection	Test/ Inspection
Isolation	Power and Signal Isolation	Test	---
Shielding	Enclosure and Cable Shielding	Test/ Inspection	Test/ Inspection
Plugs out	Powered by Spacecraft Batteries (no external power)	---	Test
Self-Compatibility	RE and RS Flight System Components Self Compatibility	---	Test
Bus Impedance	Primary Power Impedance at the EUT Interface	Test	
*MIL-STD-461F or MIL-STD-461C, as applicable.			

Europa Clipper Mission Sensitivity To Radiated Noise

- Increasing number of sensitive science instruments such as those schedule to be flown on Europa Clipper are being integrated onto spacecraft platforms that are typically qualified to MIL-STD 461C (RE02) or F (RE102)
  - Many subsystems use heritage data for the qualification process, typically from MIL-STD 461 test programs
- Instruments are increasingly being designed to be more and more sensitive.
  - Europa REASON instrument sensitivity to radiated emissions from other platform subsystems was identified as a significant risk area.
  - As clock edge rise times become faster, higher harmonics pose a bigger threat.
- Applying MIL-STD 461-type of RE102 generic specifications on payloads is not sufficient to guarantee compatibility with sensitive science instruments
  - One-size-fits-all approach incompatible with multiple subsystems and science instruments mounted on same platform in very close proximity to each other.
  - Standard RE102 1-meter emissions limit does not address all payload locations.
    - Requirements must be tailored to specific mission and spacecraft layout/configuration.
  - Payload location relative to sensitive instruments vary from project to project.
    - Those located outside a faraday cage bus pose a bigger threat, as do payloads that are in very close proximity to science instrument antennas. Payloads inside an additional faraday cage such as a bus enclosure pose less of a risk due to added shielding attenuation.

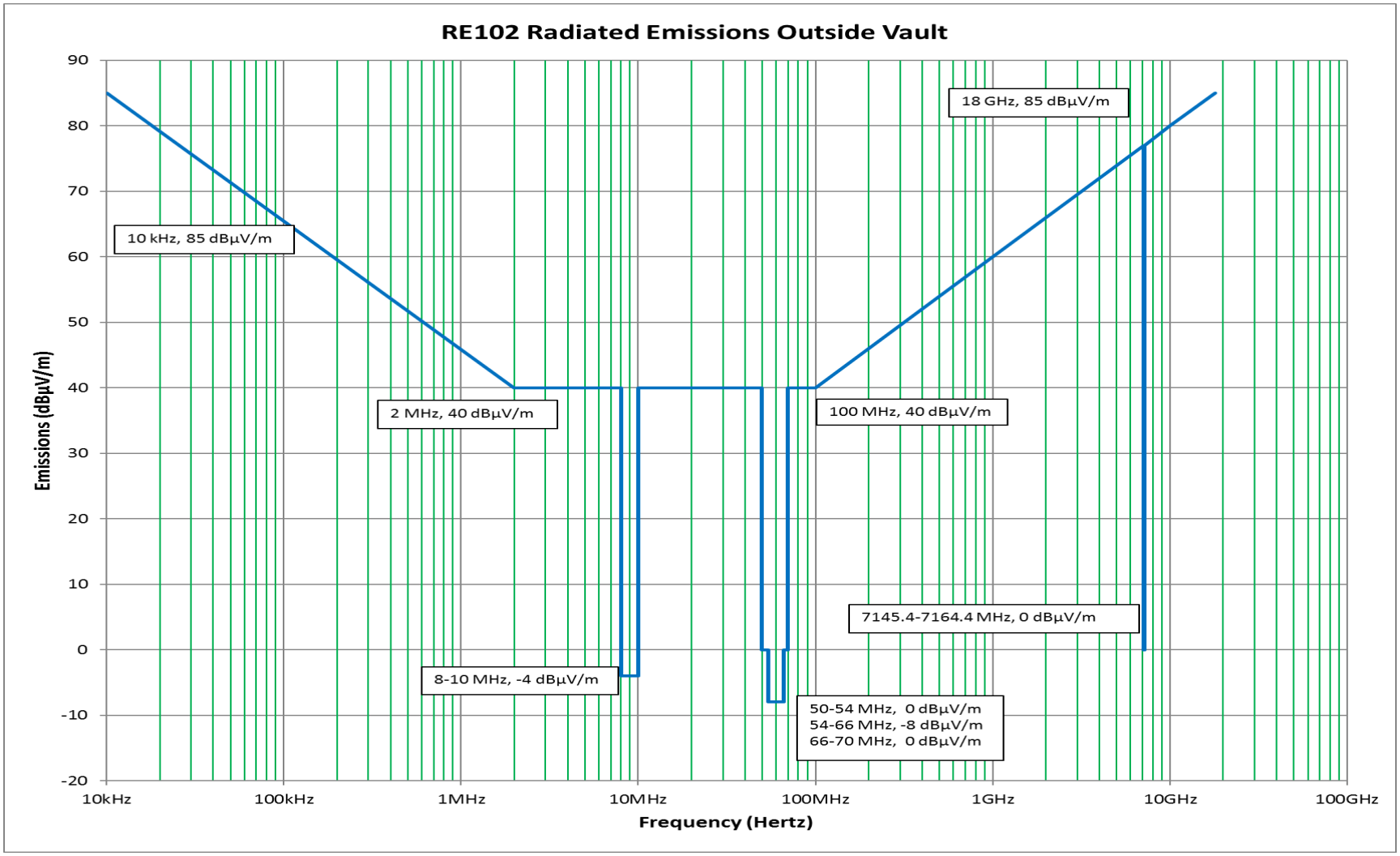
MIL-STD 461G RE102 Specs For Space System Applications

Plasma instruments operate in 30 Hz to 16 MHz range. RE102 limits not sufficient to ensure proper operation



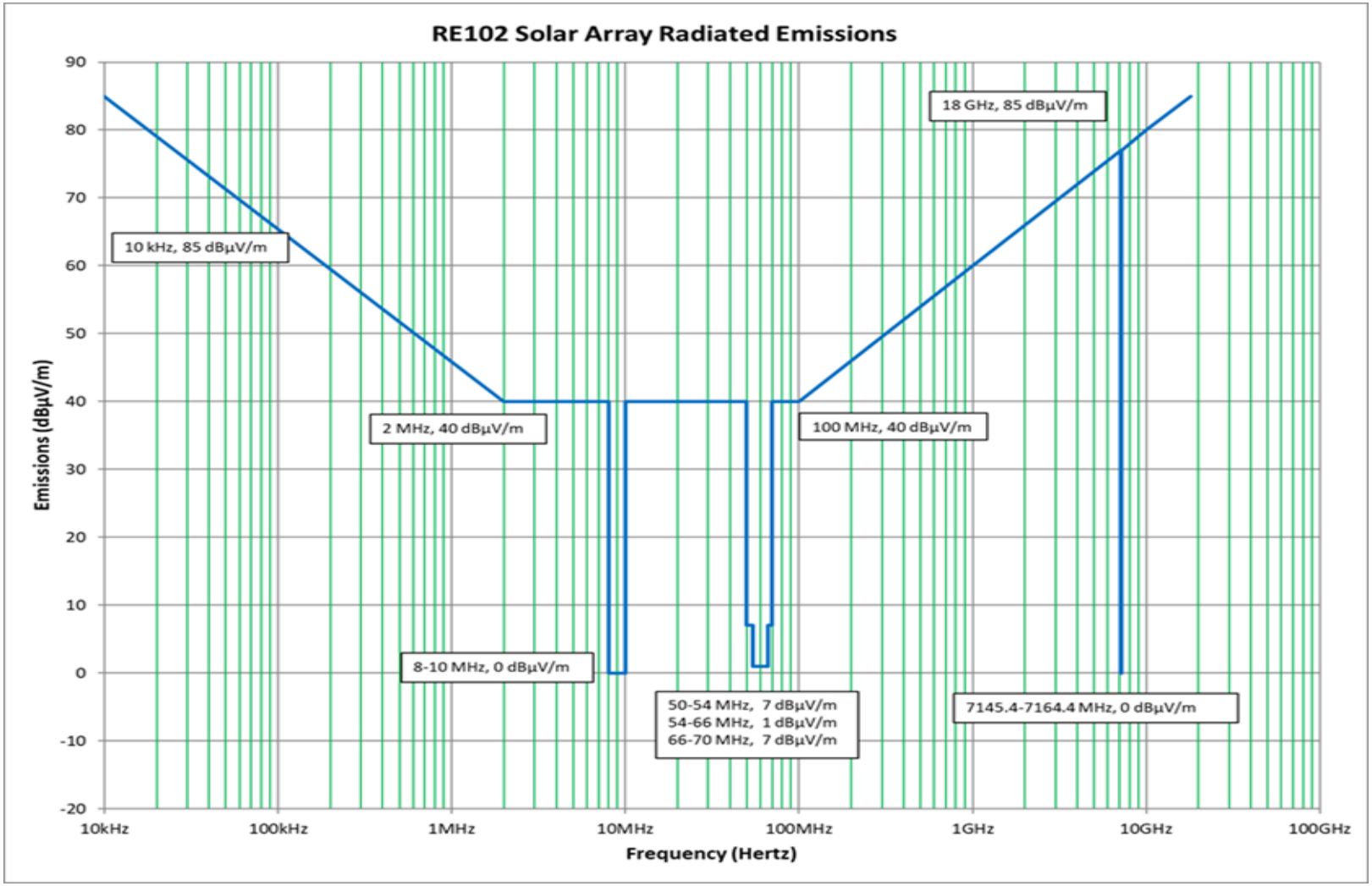
Radiometers and other sensitive science instruments operate in this frequency range. RE102 limit not sufficient to ensure proper operation.

Europa RE102 Radiated Emissions Requirements External To Vault



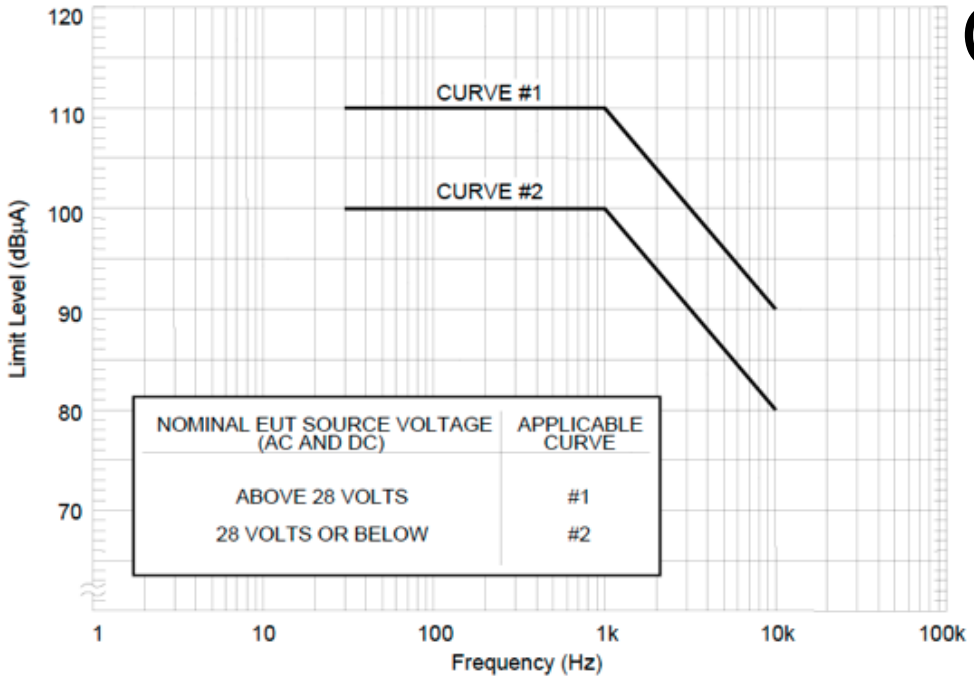
Challenging E-Field Requirements Driven by REASON

Europa RE102 Radiated Emissions Requirements For Solar Panels

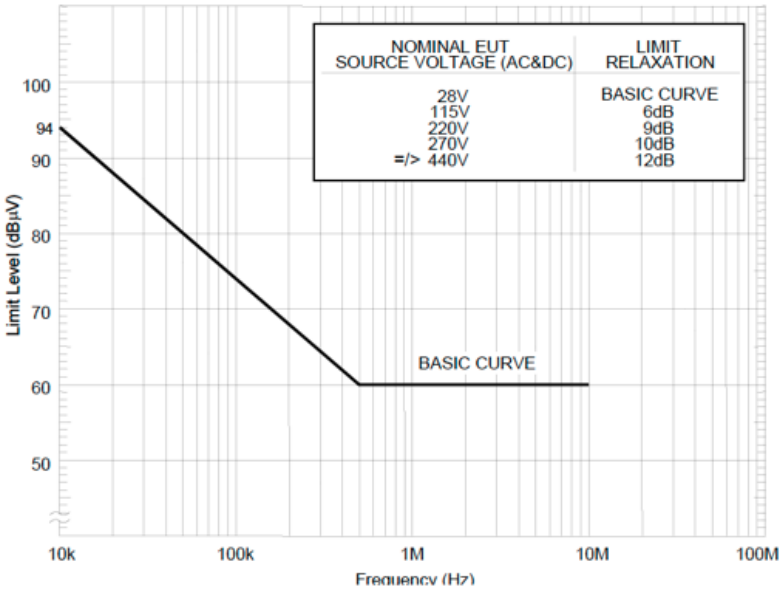


Challenging E-Field Requirements Driven by REASON

MIL-STD 461G Conducted Emissions



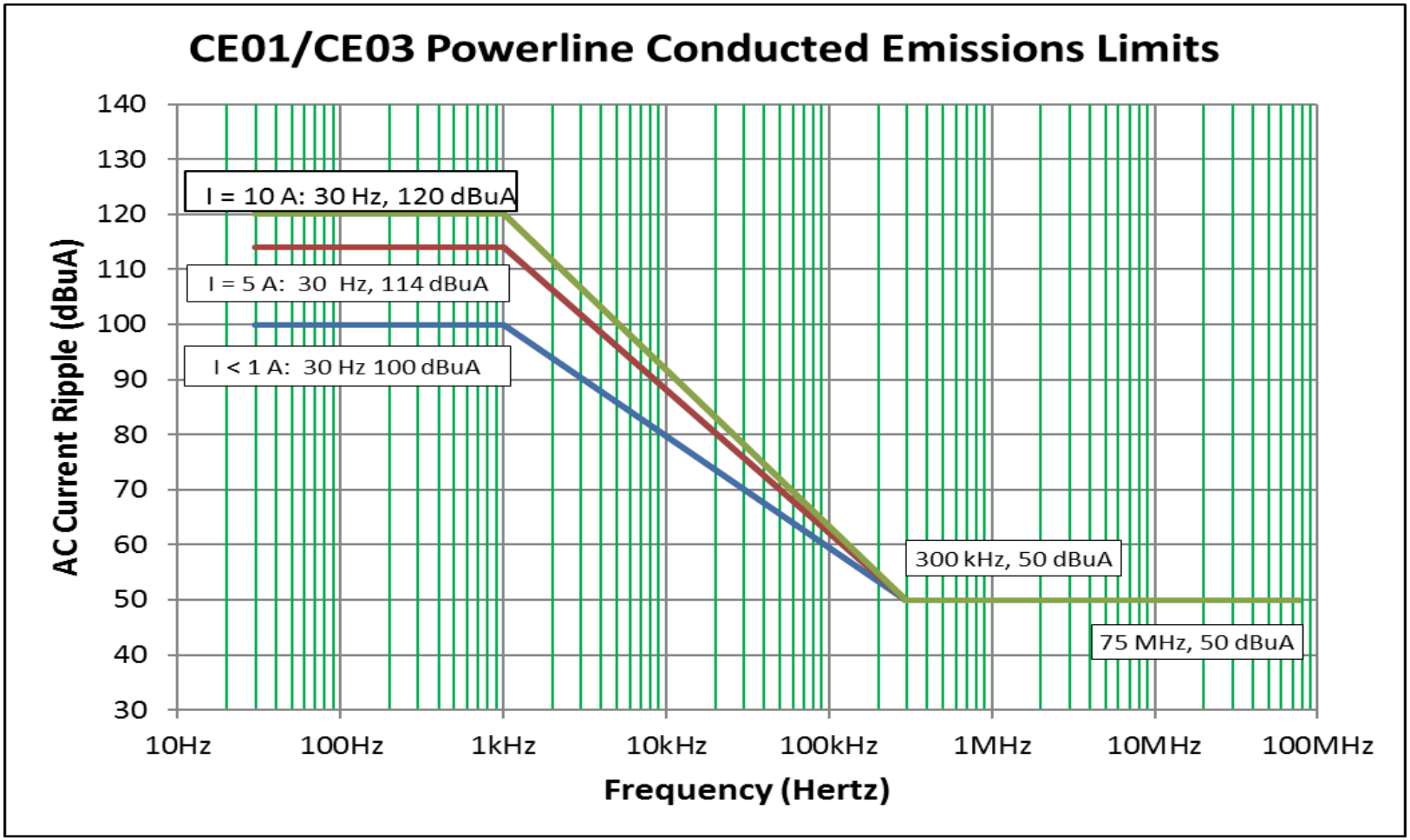
CE101 Limit



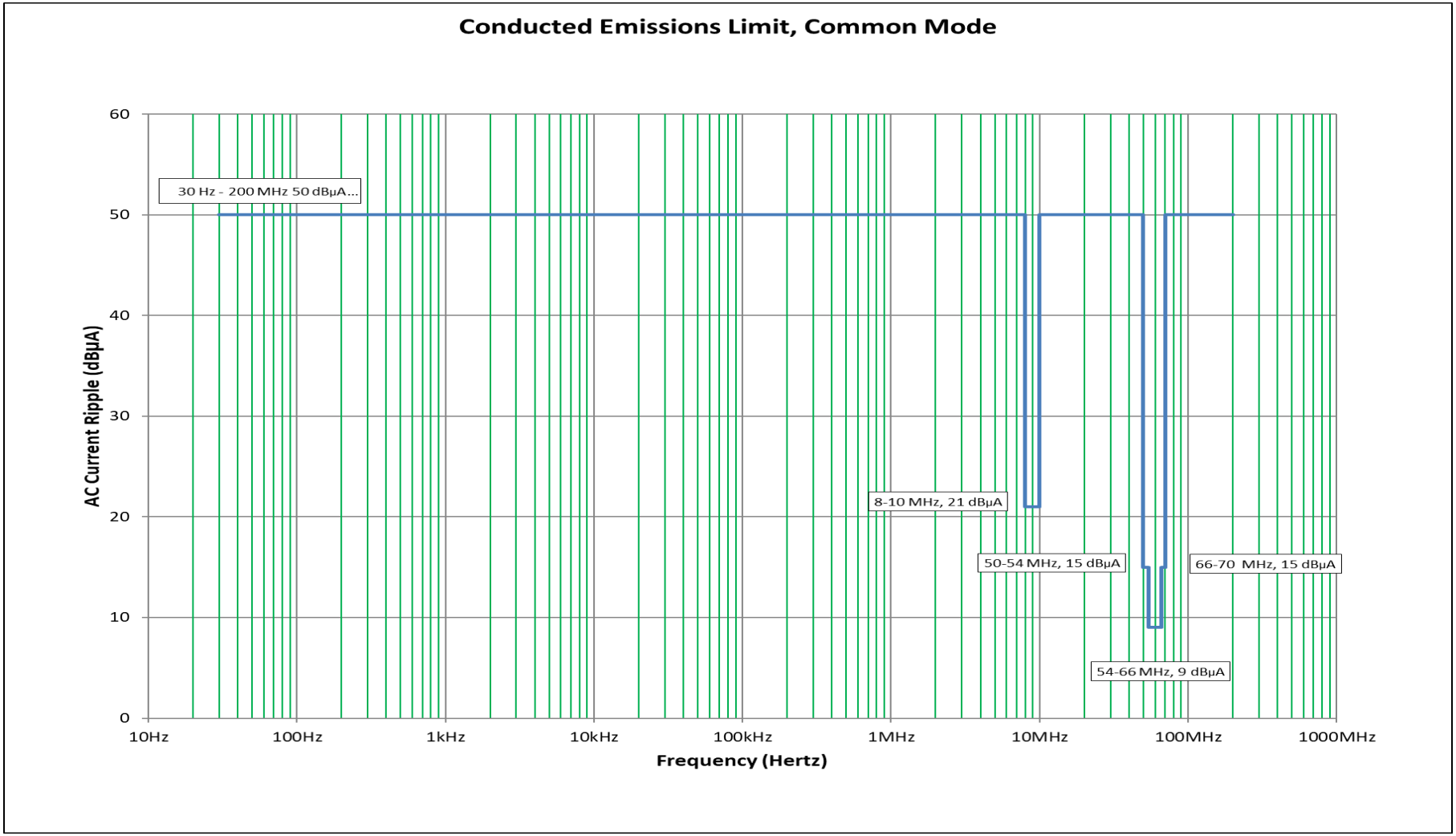
CE102 Limit

Europa Conducted Emissions

Using MIL-STD 461C Limits

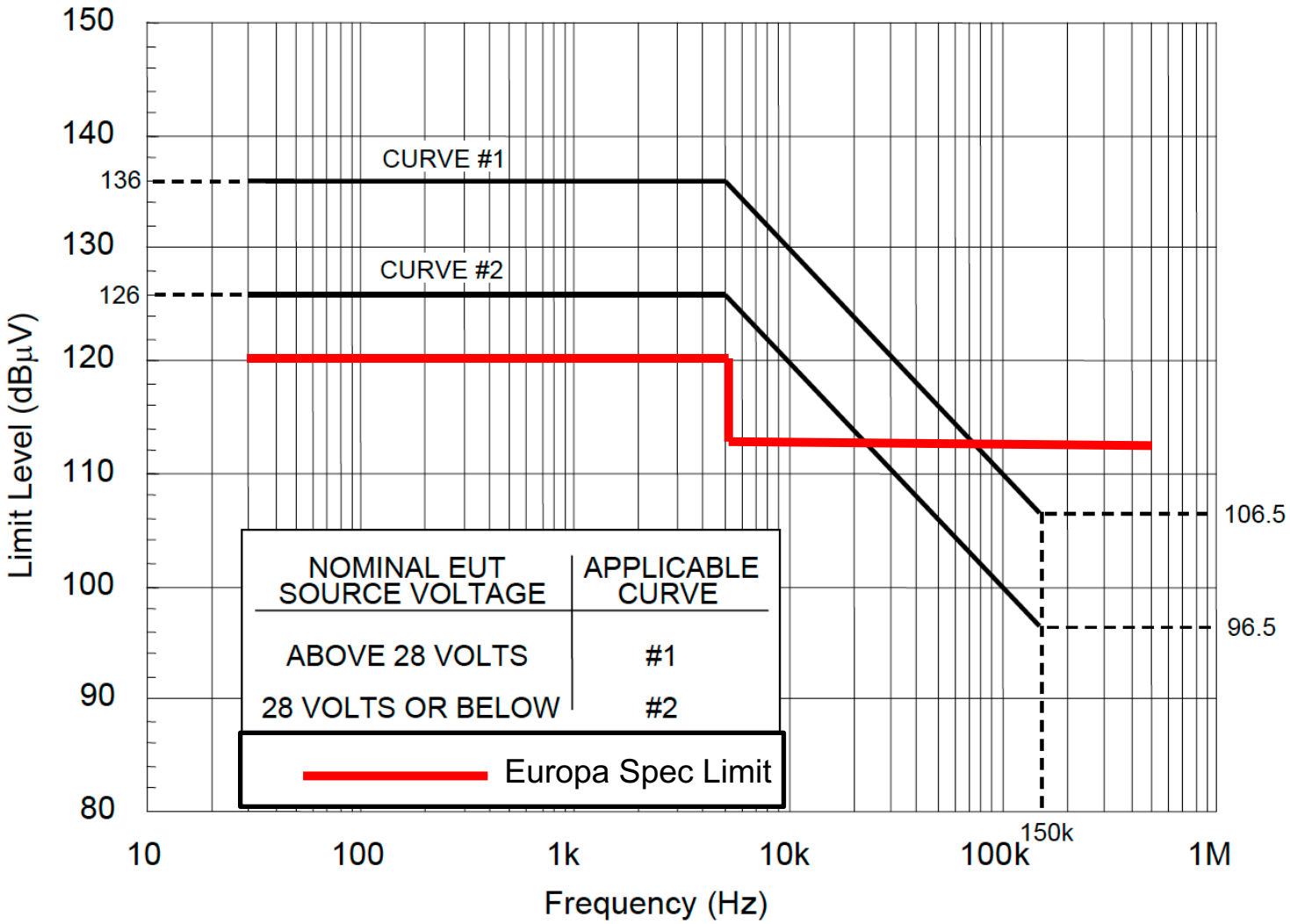


Europa Common Mode Requirements For Power Lines and Signal Lines

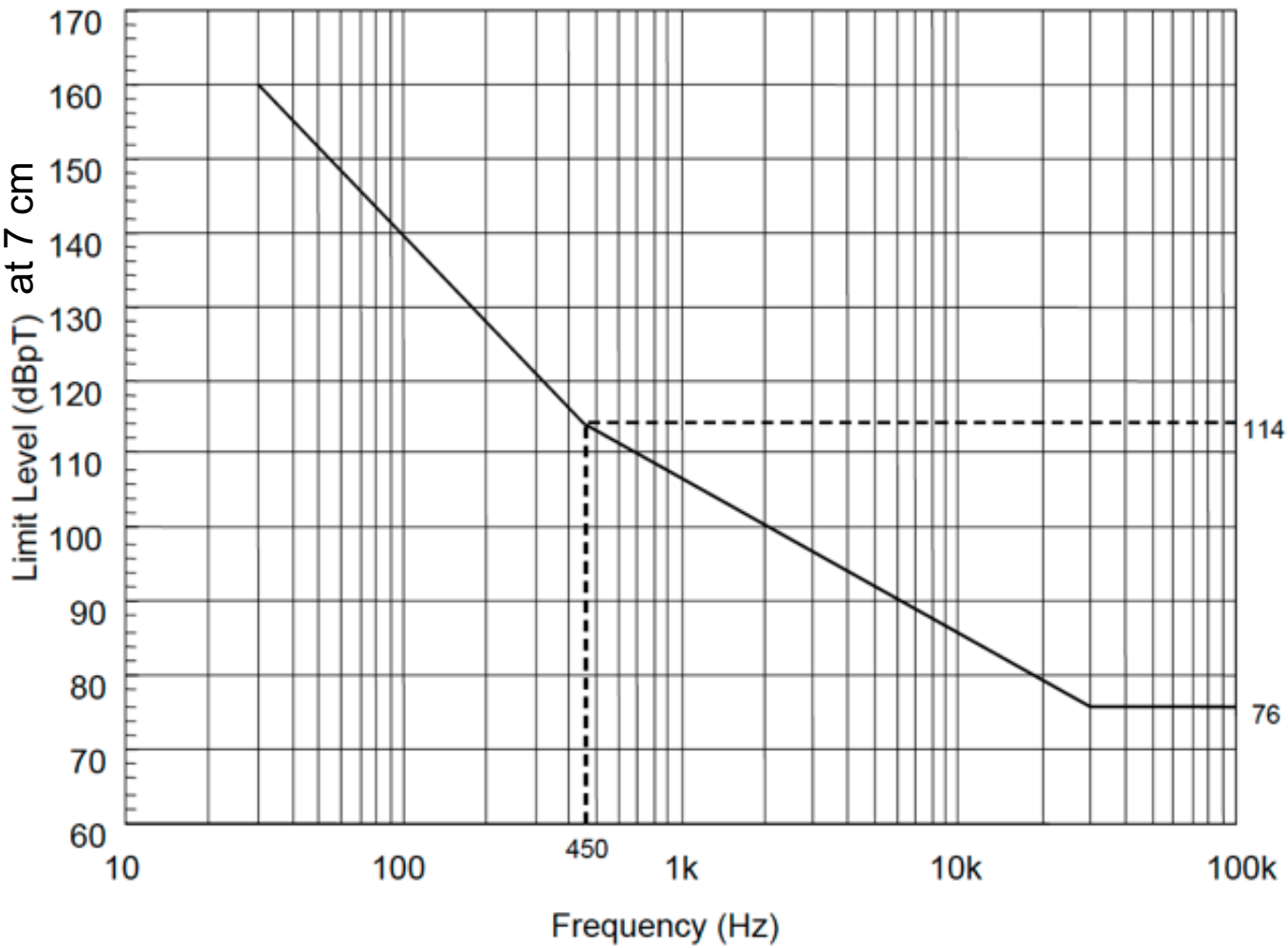


Challenging E-Field Requirements Driven by REASON

MIL-STD 461G CS101 Conducted Susceptibility Requirements

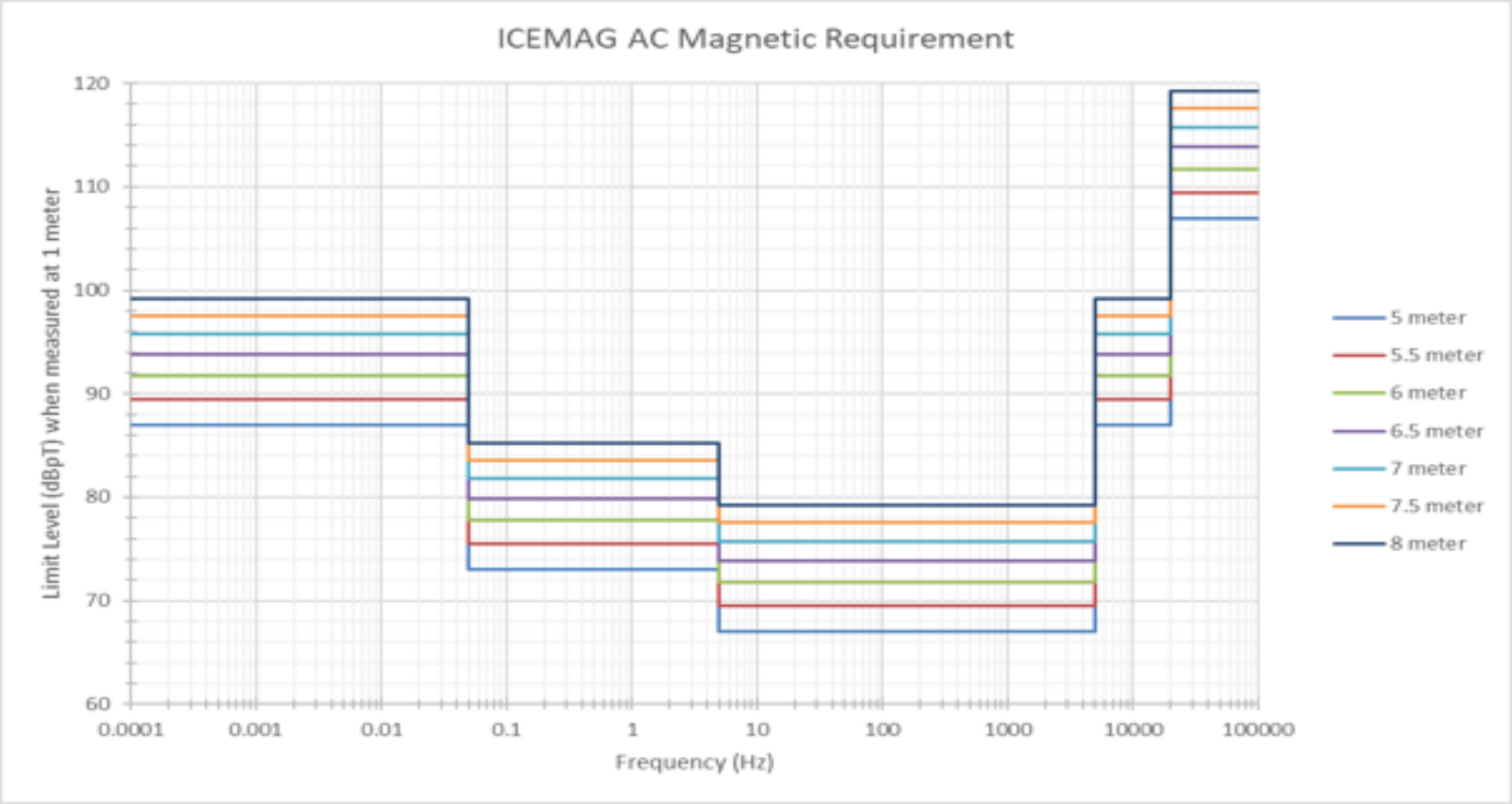


MIL-STD 461G RE101 AC Magnetic Field Emissions Requirements



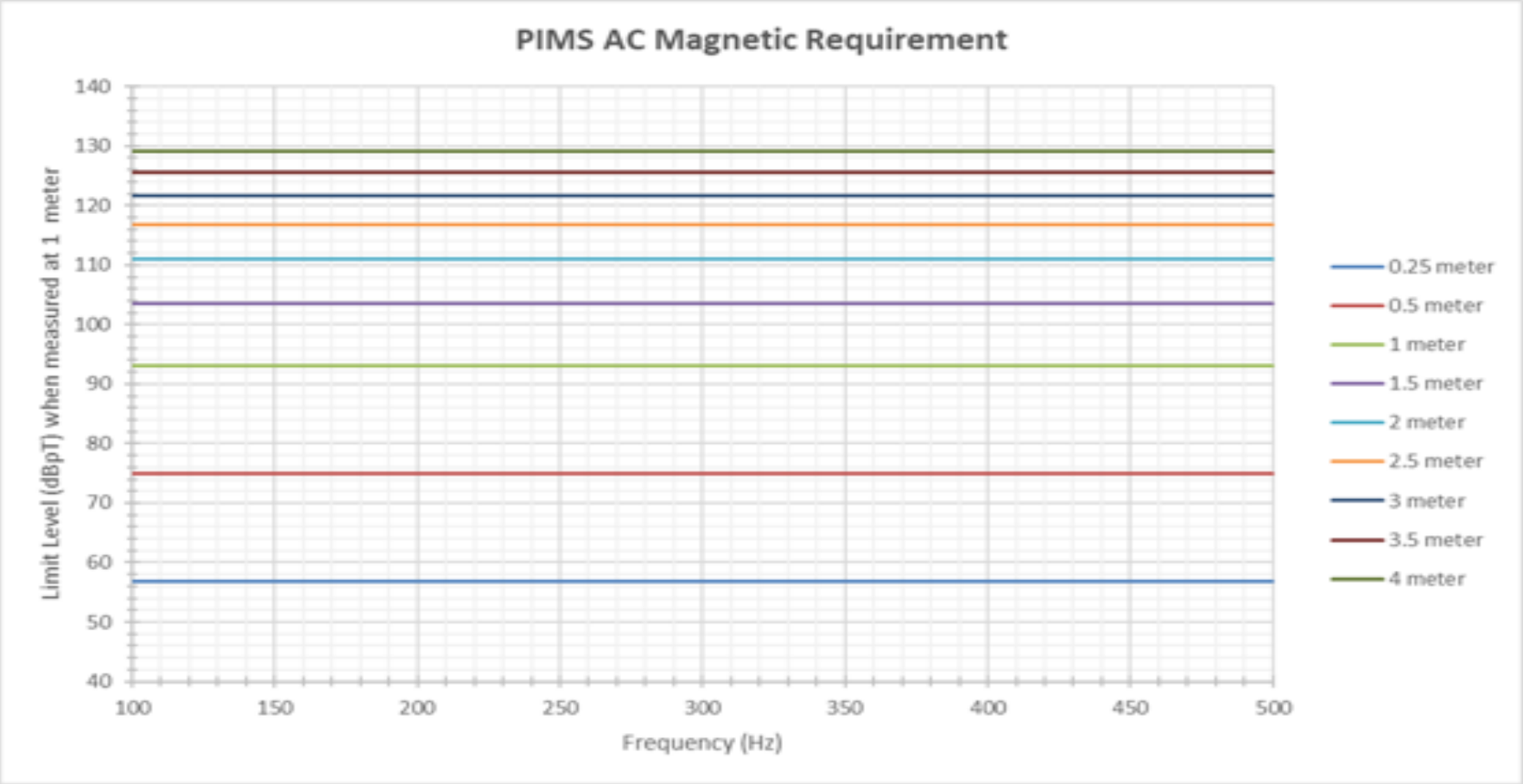
Europa Clipper AC Magnetic Requirements

- **AC Magnetic Field Emissions requirement for ICEMAG**



Europa Clipper AC Magnetic Requirements

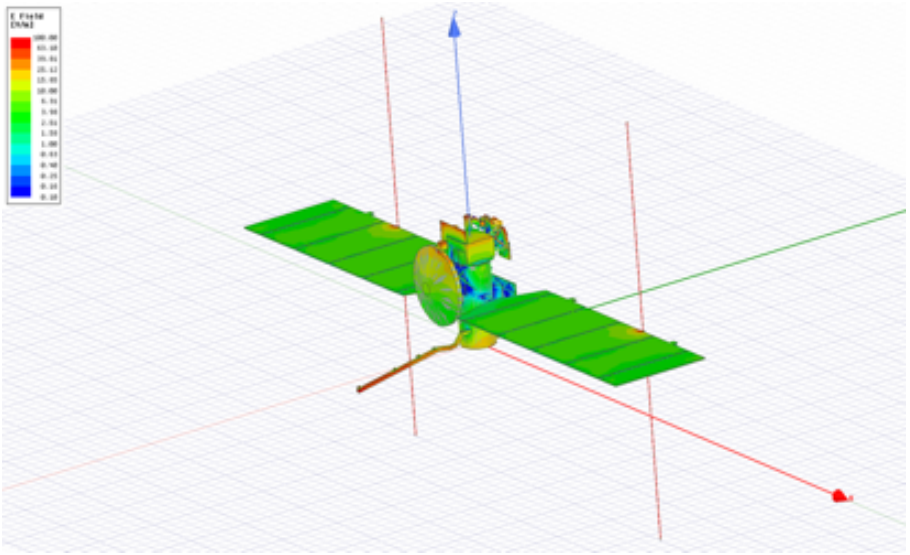
- **AC Magnetic Field Emissions requirement for PIMS**



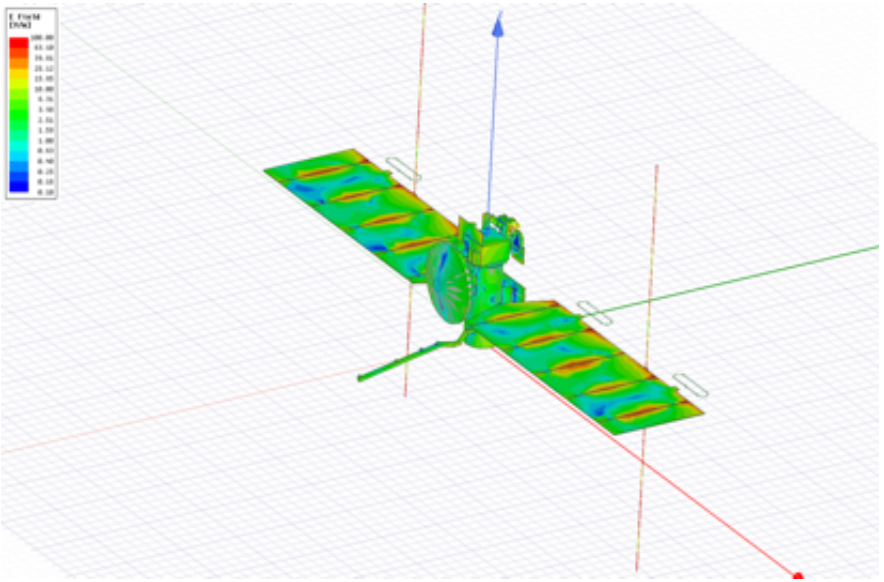
Europa Clipper RS103 Specs

- **RS requirements based on launch site transmitters and spacecraft RF models**

Radiated Susceptibility, Electric Field, 10 kHz to 18 GHz (RS103)
Operational E-Field Levels: 20 V/m from 10 kHz to 18 GHz



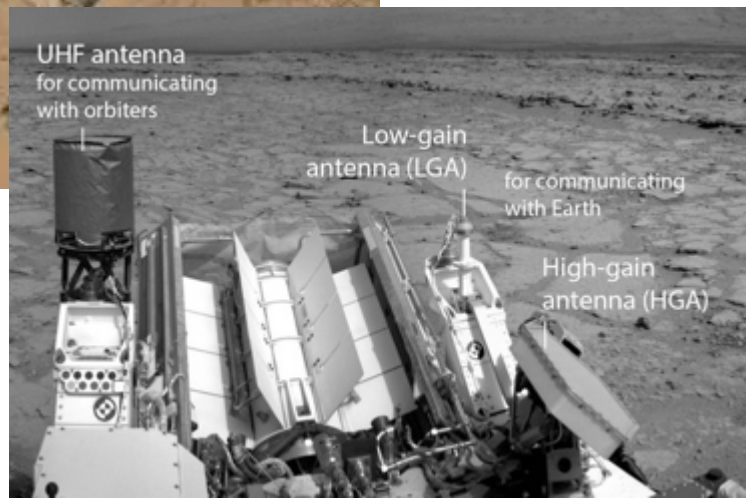
REASON 9 MHz E-Field Levels

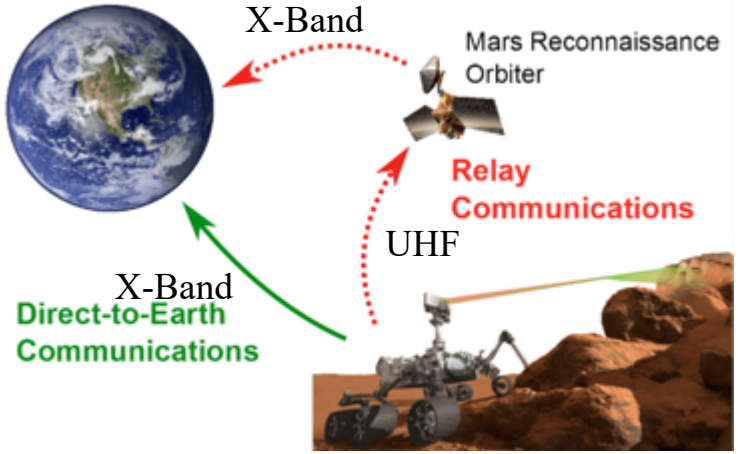


REASON 60 MHz E-Field Levels

Radiated Electric Fields
The Problem Statement

Mars Science Laboratory
Uses Two Tx/Rx To
Communicate With Earth
Receivers Operate At
X-Band at 7.14 GHz
And
UHF at 437 MHz

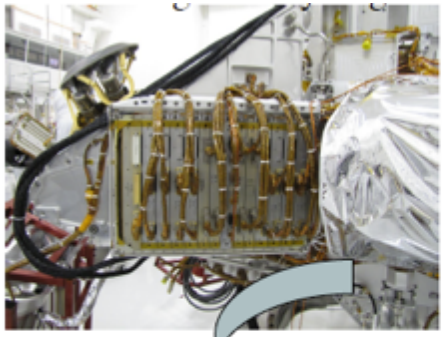


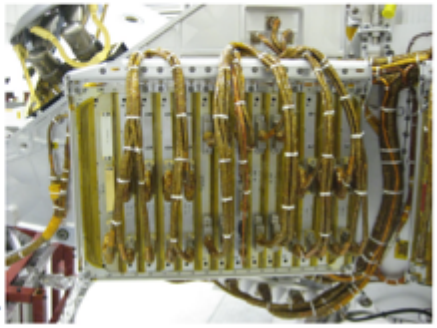


Radiated Emissions Example

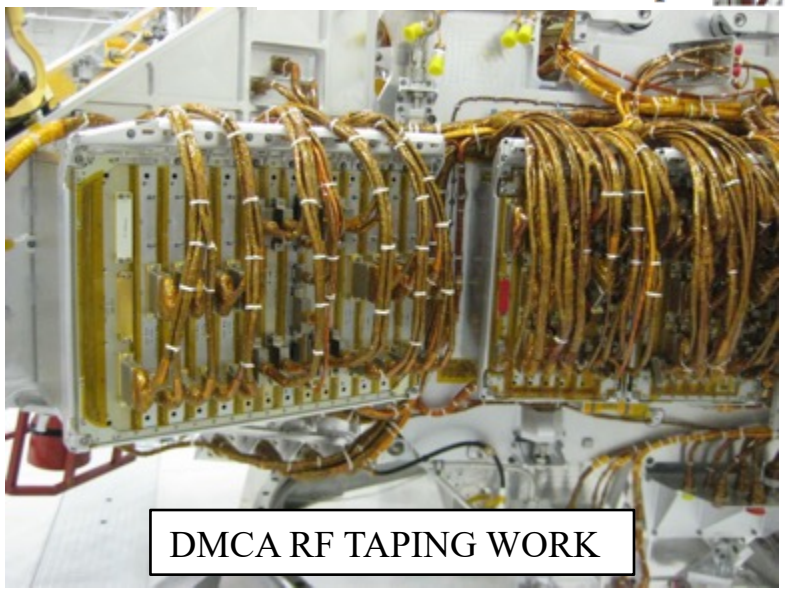
- Most JPL missions include sensitive instruments and RF receivers.
  - Limits on radiated emissions are imposed on other subsystems to reduce electromagnetic interference (EMI) on RF units.
- Radiated Emissions and Signal Integrity are considered together because they are strictly correlated.
  - Reflections of signals have the effect of increasing the radiated emissions from PCBs.
  - Switching noise produced by digital devices generate strong radiated emissions from cables attached to PCBs.
- Common mode noise increases a subsystem's radiated emissions profile and may interfere with nearby instruments and RF receivers.
  - Caused by skew, ringing, reflections, etc.
  - If operation of RF receiver and subsystem is simultaneous, impact can be significant, including loss of lock, false lock and performance degradation.

Enclosure Shielding - Seams and Penetrations





DMCA/DPAM RF Taped

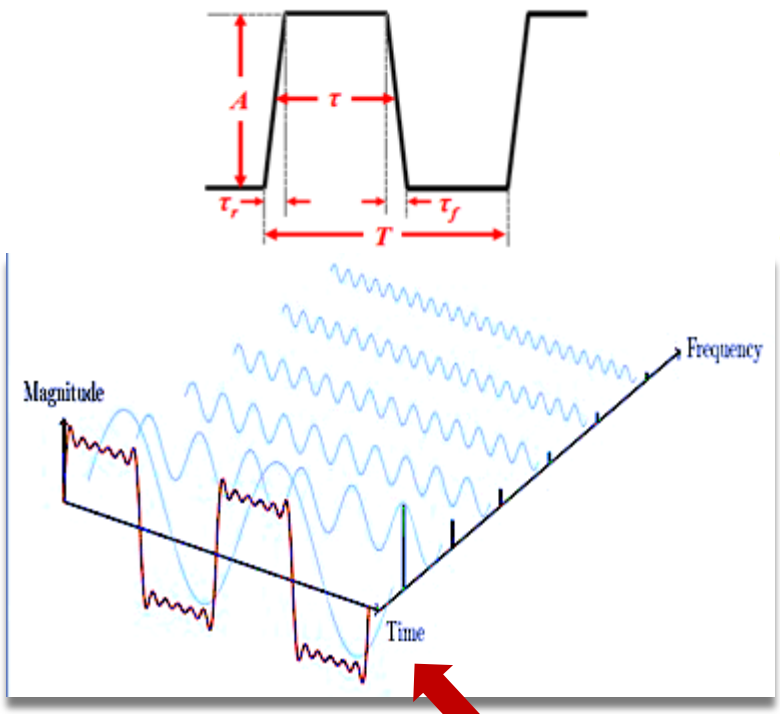


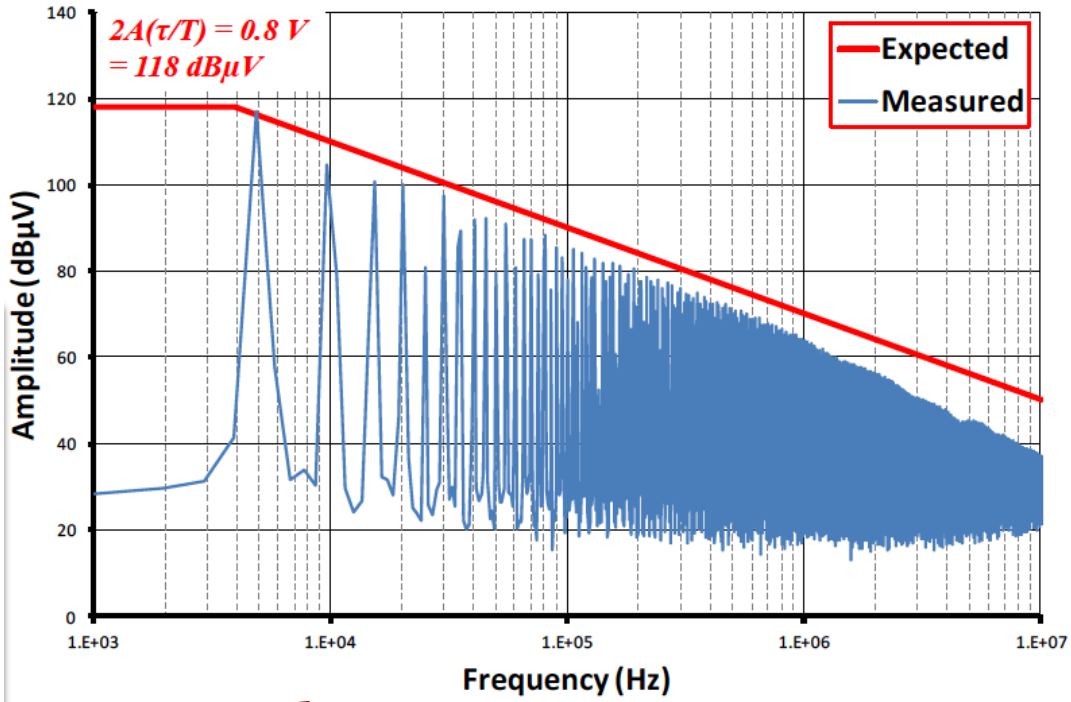
DMCA RF TAPING WORK

DMCA RF TAPING WORK

Radiated Emissions Example

TYPICAL SPECTRUM OF PULSE





Time Domain Mapping Into Frequency Domain

Courtesy John McCloskey
EMC Chief Engineer
At NASA-GSFC

Radiated Emissions Example

Radiated Emissions In LVDS

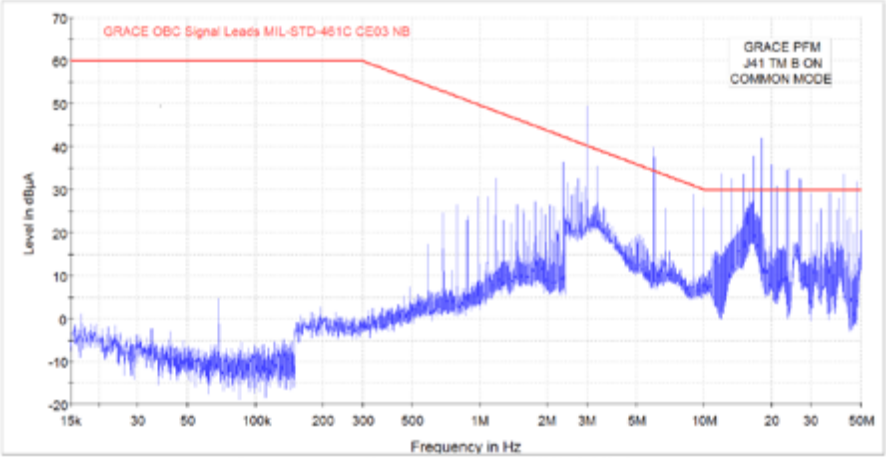
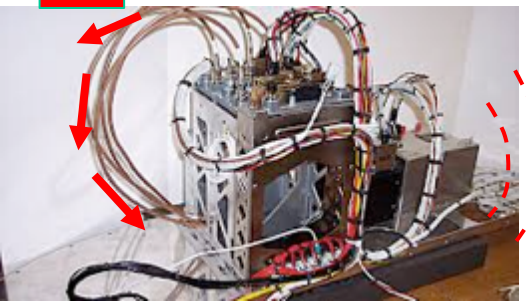


Figure 3.2-3. J41 CECM Data, PFM OBC

Common Mode Noise Works Its Way To Efficient Antenna Elements Such As Cables, Slots, Connectors Etc…

SI



EMI

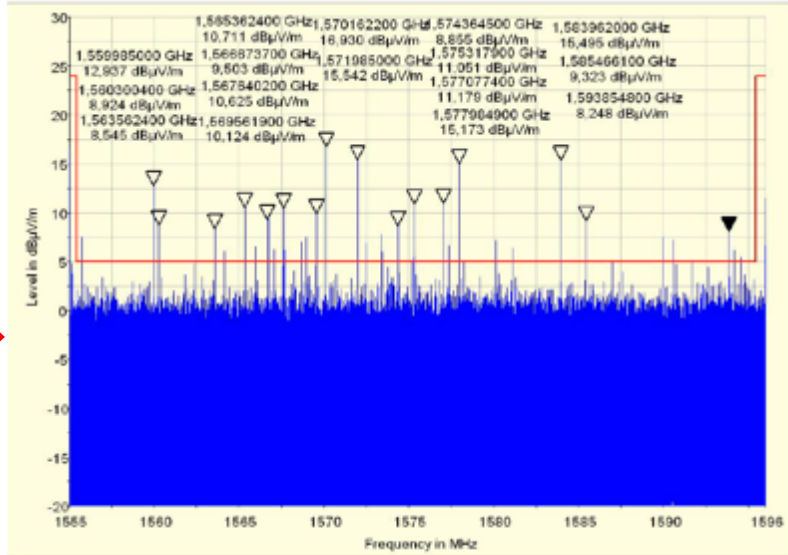
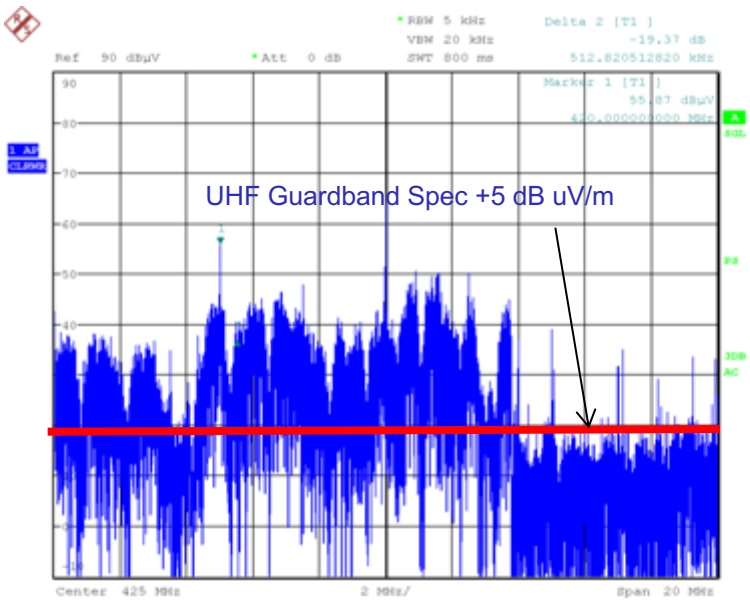


Figure 3.3-1. OBC PFM RE02 Data, GPS L1 Band, Vertical Polarity

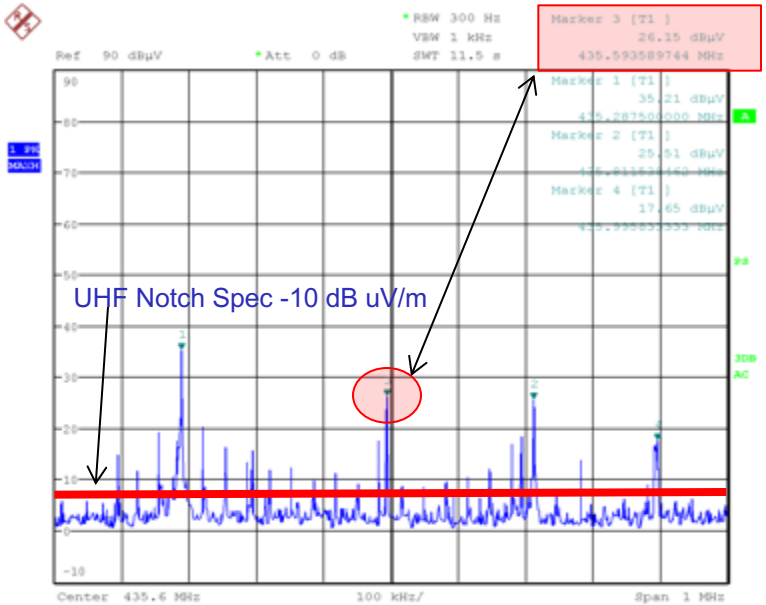
…Resuting In Radiated Emissions In Sensitive Receiver Bands Such As GPS L1, Or UHF Or S-Band....

MARS CURIOSITY UHF INTERFERENCE PROFILE



gygjhgj
Date: 31.MAR.2011 21:43:32

False Locks, MAHLI Camera On, General UHF Range

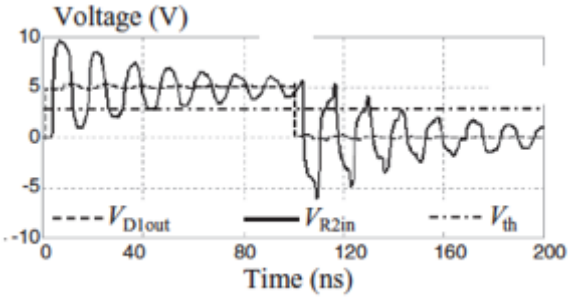


gygjhgj
Date: 1.APR.2011 22:06:55

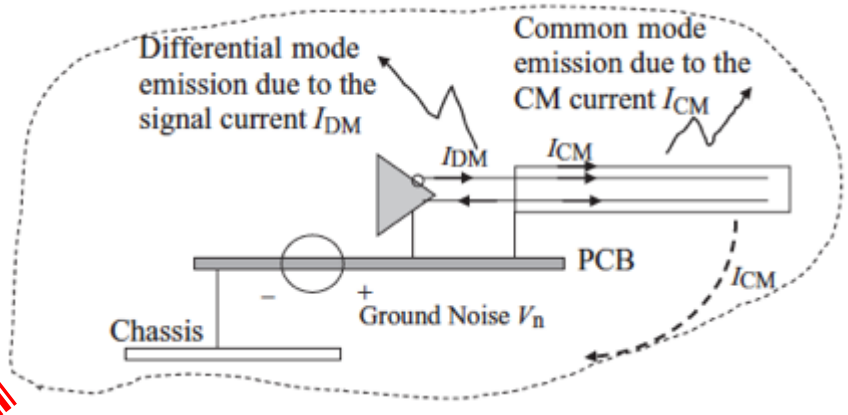
Channel 1, 435.6 MHz Other Cameras On, UHF False Locks

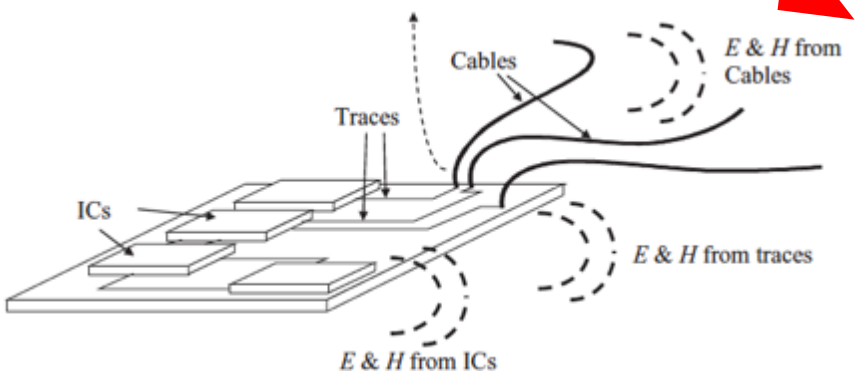
Common Mode Noise = RE

Poor Signal Integrity PCB Design….



Leads To Common Mode Noise…





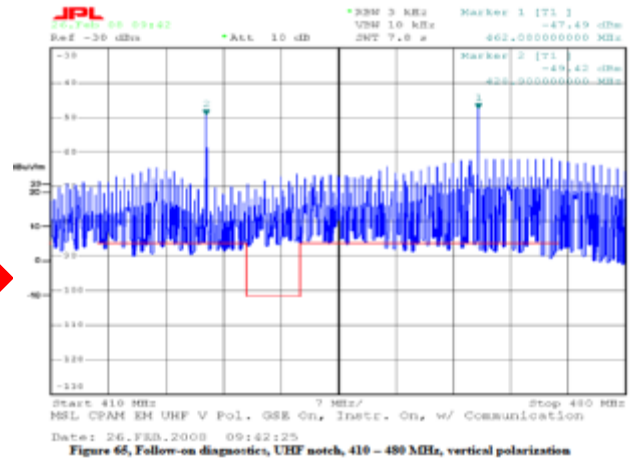


Figure 65, Follow-on diagnostics, UHF notch, 410 – 480 MHz, vertical polarization

Which Leads To PCB Radiated EMI Noise

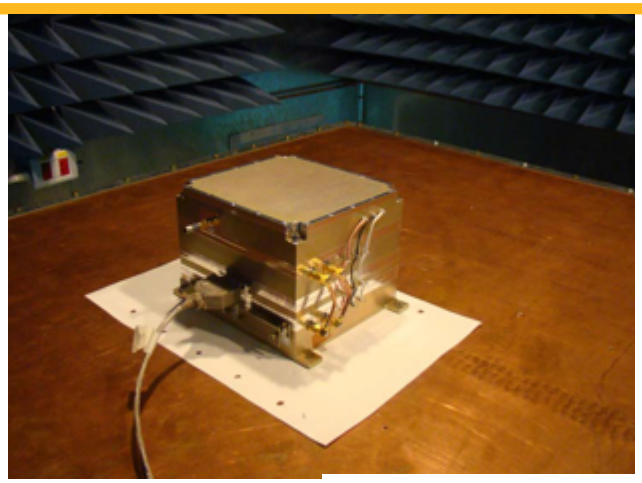
Impacting Sensitive RF Receivers

SAC-D/Aquarius RE Requirements

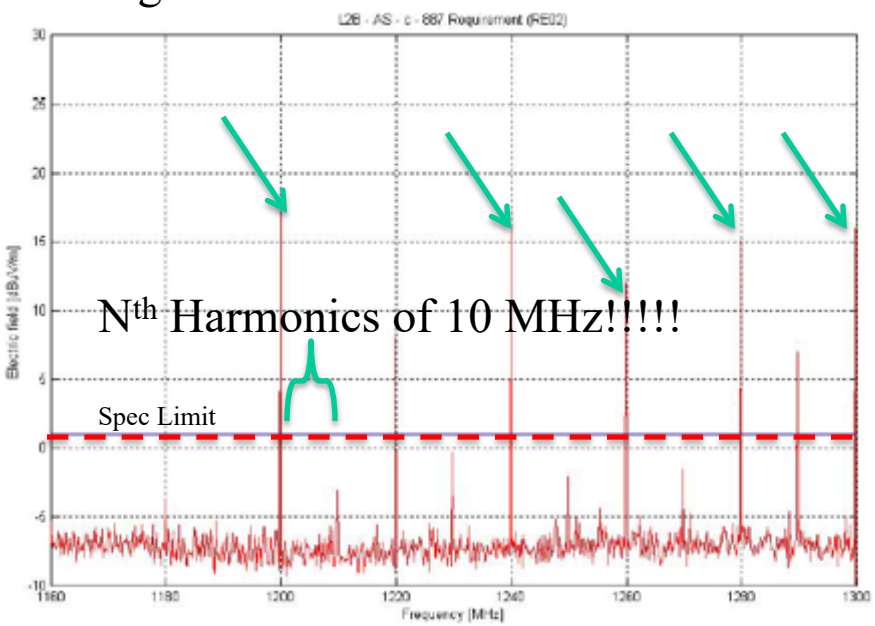
A narrowband EMI source has an effective noise temperature

$$dT_N = \frac{dP_{EMI}}{kB}$$

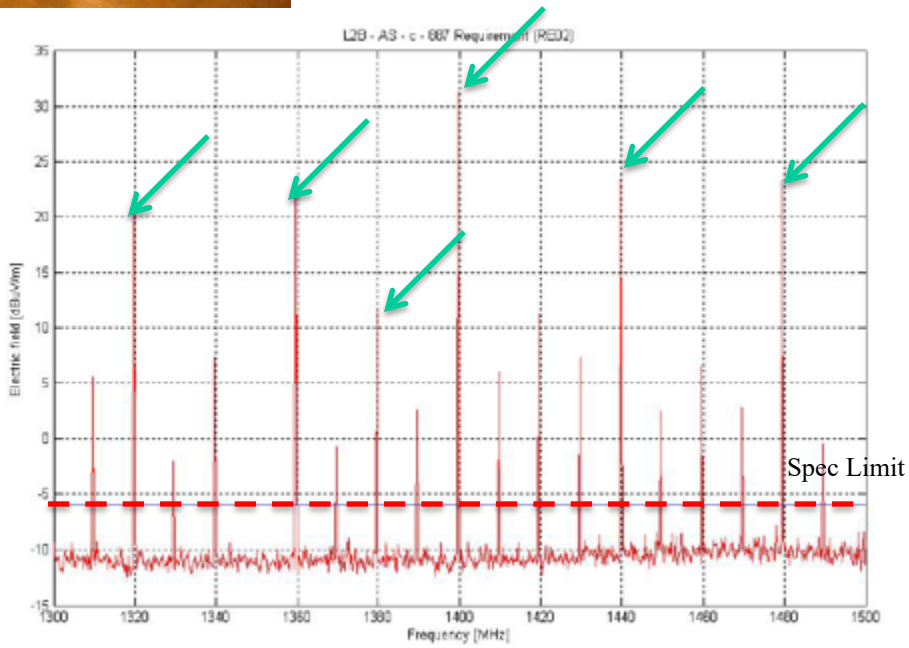
Radiometer can detect this "Signal" if it is large enough



Typical SAC-D Box Digital Collection System (DSC)



Scatterometer Band



Radiometer Band

THANK YOU!