CubeRRT: CubeSat Radiometer RFI Technology Validation Mission

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NASA GSFC

NASA Earth Science Technology Forum

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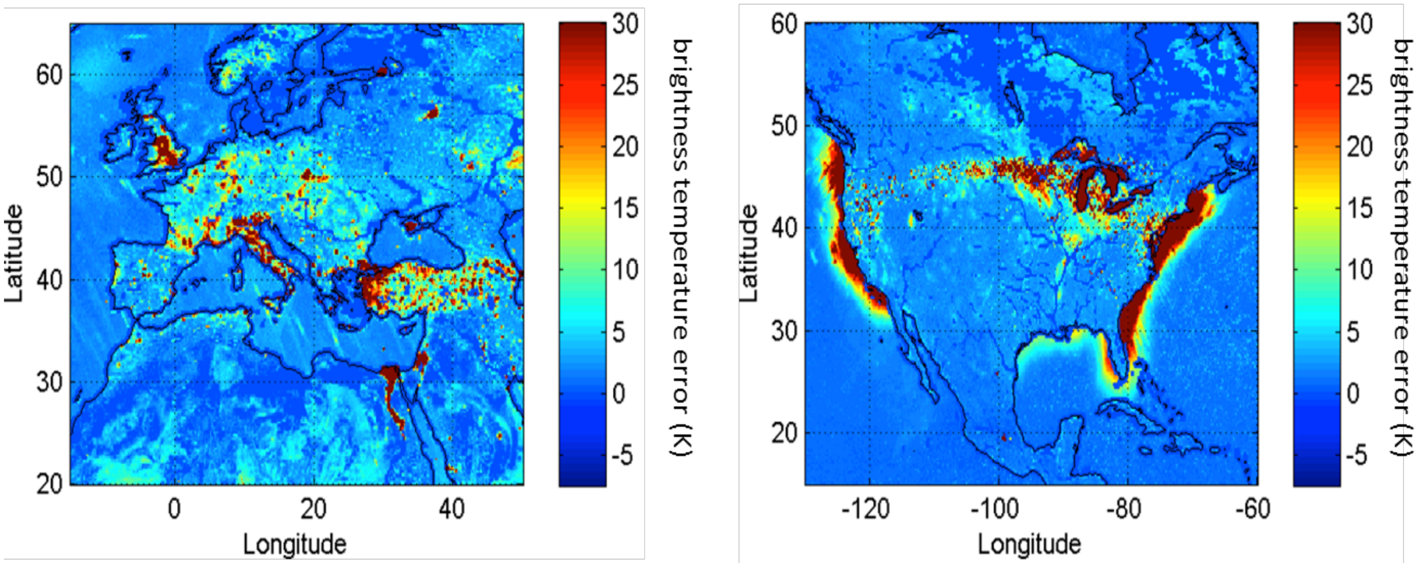
RFI Problem for Microwave Radiometry

- Microwave radiometers are important Earth Observing systems for a variety of science applications (land, ocean, atmosphere, …)
- Observe the naturally generated microwave thermal emission from Earth
  - Man-made transmissions cause radio-frequency interference (RFI)

GMI Images at 10.7 (left) and 18.7 (right) GHz showing RFI 'hot spots'



Radiometers avoid RFI (ideally) by operating in frequency bands where transmission is prohibited

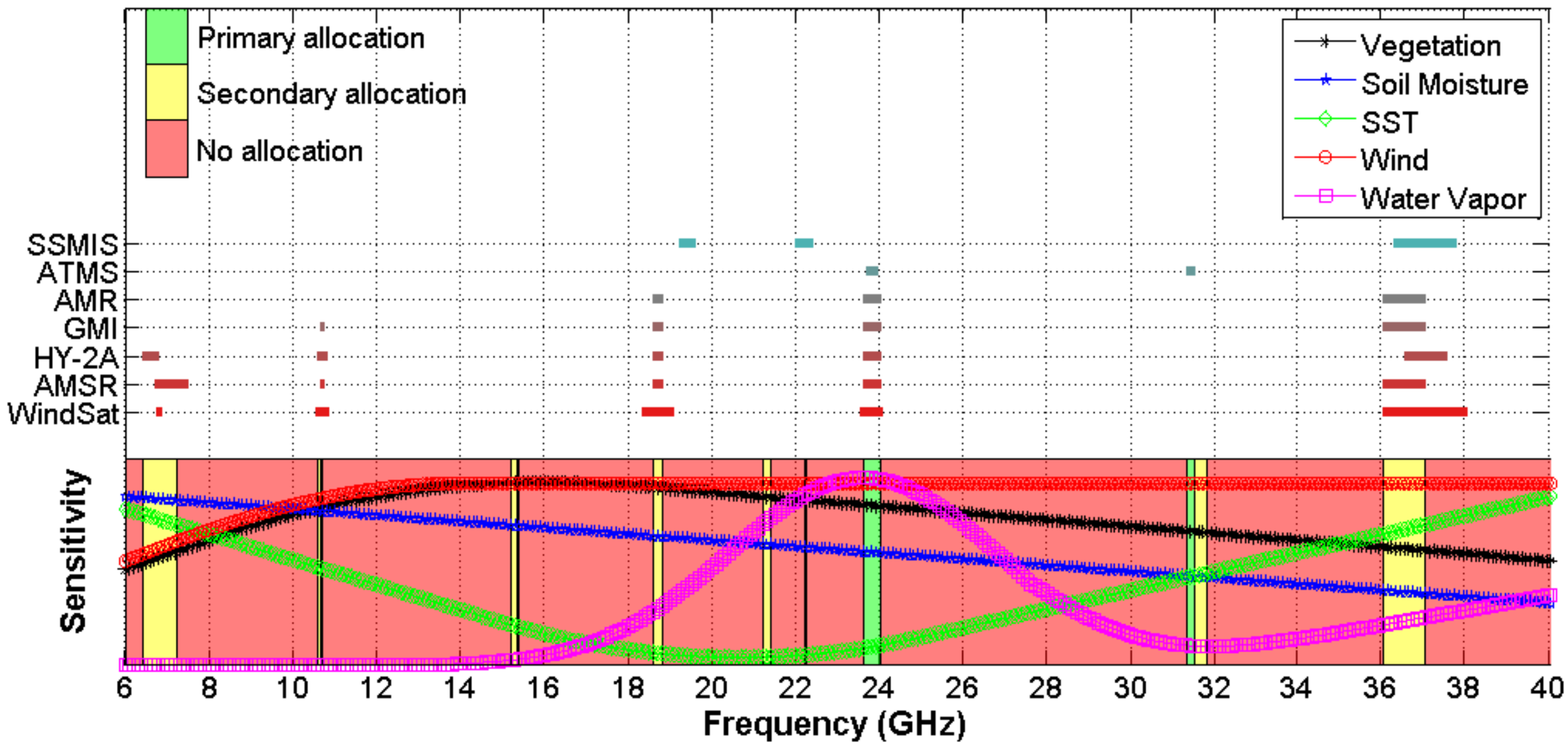
- SMAP 1% of measurements have RFI > 30K, 10% have RFI > 3K (in a protected band!)

Recent Progress in Addressing RFI

- RFI problem has been recognized over many years, and ESTO has supported technology development to make progress
  - Multiple IIP's, ACT's, and AITT 2002-2010 developed digital backends and algorithms for radiometry to detect and filter out RFI corrupted data
  - Project team members collaborated throughout these programs
- Technology infused into SMAP's L-band radiometer digital backend currently operating successfully in space
  - Project team members designed, developed, tested, and validated SMAP digital backend
- RFI problem is even more challenging for future radiometer systems

	SMAP	Future
Number of bands	1	6 or more
Bandwidth	20 MHz	100's of MHz in each channel
RFI Processing on ground?	Yes (limited downlink volume)	Not possible (downlink volume too high)
RFI Processing on-board spacecraft?	No; not necessary	Yes; only way to address RFI challenge for future systems

Spectrum Allocations 6-40 GHz



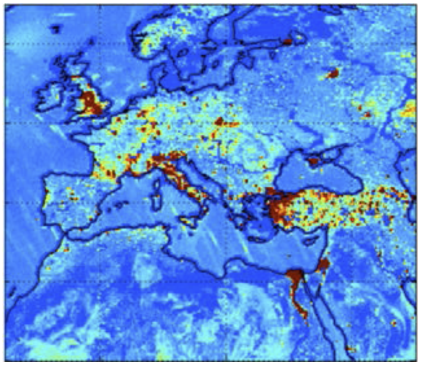
- Secondary allocations of limited utility
- Current missions are operating outside protected bands and experiencing RFI
  - As spectrum use increases, problem will become worse: future radiometry missions (SCLP, GPM follow on, …) may become impossible
  - Worst case is weak RFI that makes its way into science products

CubeRRT: CubeSat Radiometer Radio Frequency Interference Technology Validation

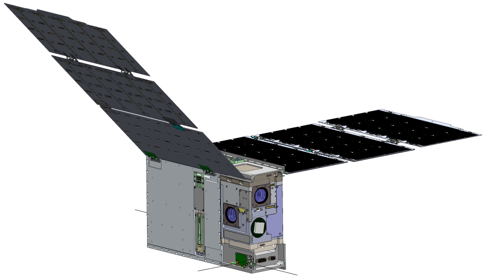
PI: Joel T. Johnson, Ohio State University

Objective

- Demonstrate wideband radio frequency interference (RFI) mitigating backend technology for future spaceborne microwave radiometers operating 6 to 40 GHz
- Crucial to maintain US national capability for spaceborne radiometry and associated science goals
- Demonstrate successful real-time on-board RFI detection and mitigation in 1 GHz instantaneous bandwidth
- Demonstrate reliable cubesat mission operations, include tuning to Earth Exploration Satellite Service (EESS) allocated bands in the 6 to 40 GHz region



RFI sources in Europe at 10.7 GHz observed by GPM Microwave Imager



Nominal CubeRRT Configuration

Approach

- Build upon heritage of airborne and spaceborne (SMAP) digital backends for RFI mitigation in microwave radiometry
- Apply existing RFI mitigation strategies onboard spacecraft; downlink additional RFI data for assessment of onboard algorithm performance
- Integrate radiometer front end, digital backend, and wideband antenna systems into 6U CubeSat
- CSLI launch from ISS into 400 km orbit; ~ 120-300 km Earth footprint for RFI mitigation validation
- Operate for one year at 25% duty cycle to acquire adequate RFI data

Co-Is/Partners:

C. Chen, M. Andrews, OSU; S. Misra, S. Brown, J. Kocz, R. Jarnot, JPL; D. Bradley, P. Mohammed, J. Lucey, J. Piepmeier, GSFC

Key Milestones

• Requirements definition and system design	03/16
• Instrument engineering model subsystem tests	10/16
• Instrument engineering model integration and test	12/16
• Instrument flight model subsystem tests	04/17
• Instrument flight model integration and test	06/17
• Spacecraft integration and test	12/17
• CubeRRT launch readiness	01/18
• On-orbit operations completion	L+12 months

TRL_{in} = 5 TRL_{out} = 7

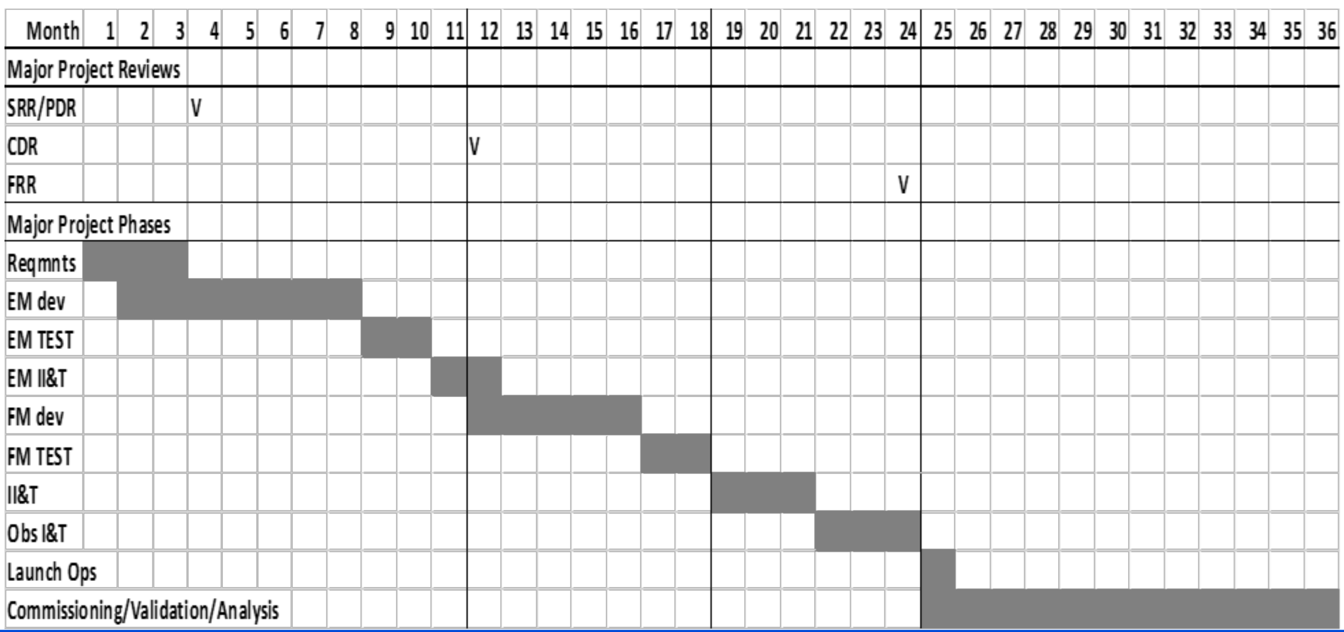
ESTO Earth Science Technology Office

CubeRRT Mission Properties

Frequency	6 to 40 GHz Tunable, 1 GHz instantaneous Operations emphasize nine bands commonly used for microwave radiometry
Polarization	Single polarization (Left Hand Circular)
Observation angle/Orbit (ISS launch)	0° Earth Incidence Angle 400 km altitude, 51° orbit inclination
Spatial Resolution	120 km (40 GHz) to 300 km (6 GHz)
Integration time	100 msec
Ant Gain/Beamwidth	15dBi/40° (6 GHz), 23 dBi/16° (40 GHz)
Interference Mitigation	On-board Nyquist sampling of 1 GHz spectrum; On-board real-time Kurtosis, Pulse, and Cross-Frequency Detection Downlink of frequency resolved power and kurtosis in 128 channels to verify on-board performance
Calibration (Internal)	Reference load and Noise diode sources
Calibration (External)	Cold sky and Ocean measurements
Noise equiv dT	0.8 K in 100 msec (each of 128 channels in 1 GHz)
Average Payload Data Rate	9.375 kpbs (including 25% duty cycle) ~102 MB per day,~ 37 GB over 1 year mission life
Downlink	135 MB per daily ground contact [6 minute contact with 3 Mbps UHF cadet Radio] 32% margin over payload data

CubeRRT Development Overview

- Engineering Model (EM) development, integration, and testing
  - Year 1 activity
  - Concludes with CDR (early 2017)
- Flight Model (FM) development, integration, and testing
  - Year 2 activity
  - Concludes with flight ready system ready for launch (end 2017)
- Mission operations
  - Year 3 activity



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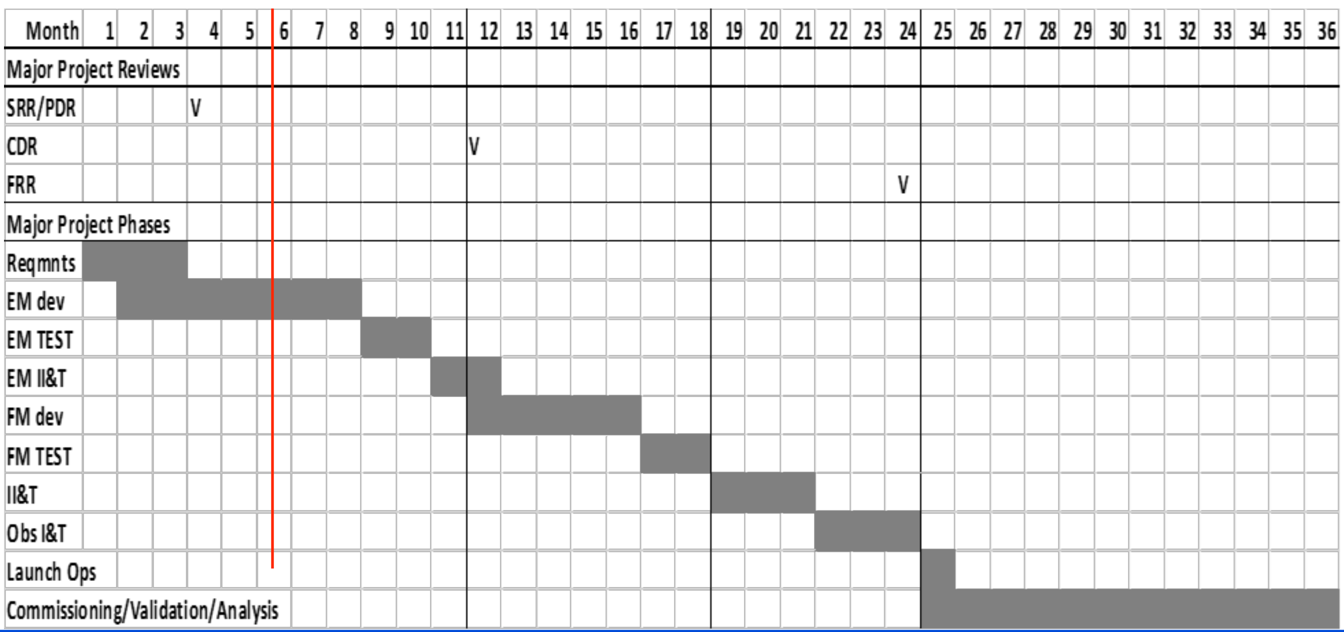


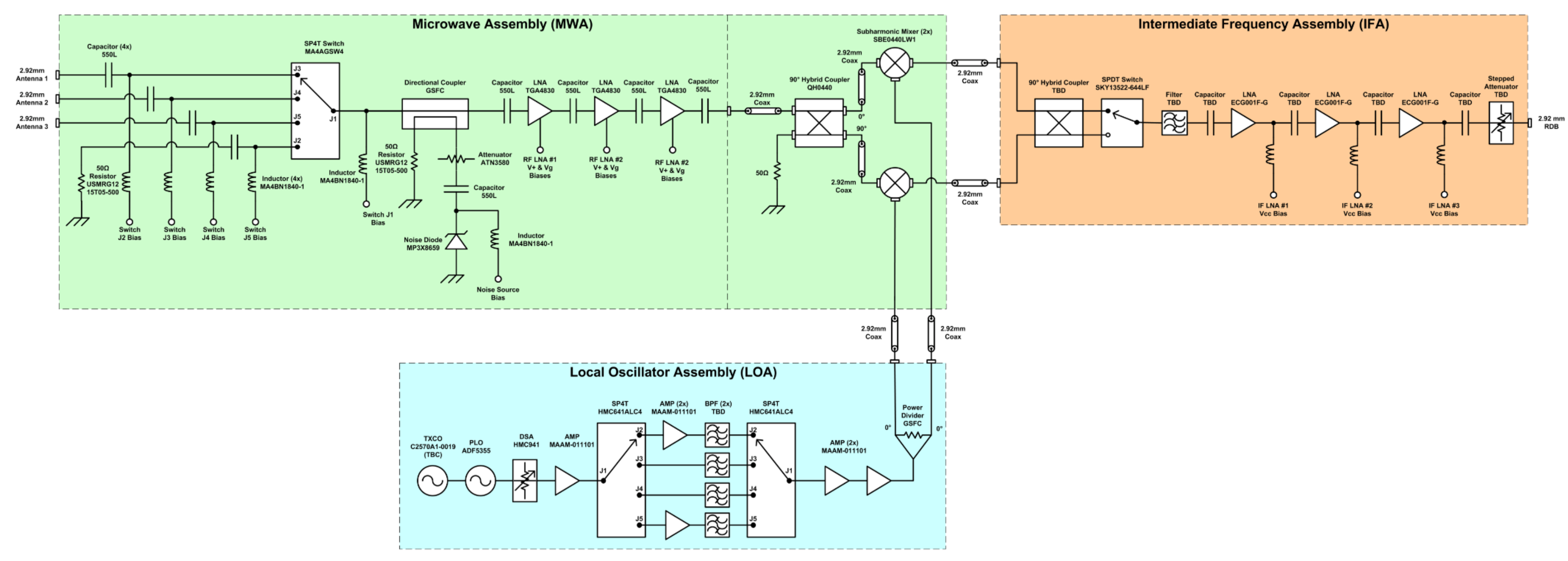
CubeRRT Subsystems and Team

- Ohio State University (OSU) lead for payload/spacecraft system integration and test procedures

- CubeRRT payload consists of 3 subsystems:
  – Radiometer Front End (RFE)
    - Design, development, test by NASA Goddard Space Flight Center (GSFC)
  – RF Digital Backend (RDB)
    - Design, development, test by NASA Jet Propulsion Laboratory (JPL)
  – Antenna (ANT)
    - Design, development, test by OSU

- CubeRRT spacecraft bus (SC)
  – Design, development, test by Blue Canyon Technologies (BCT)

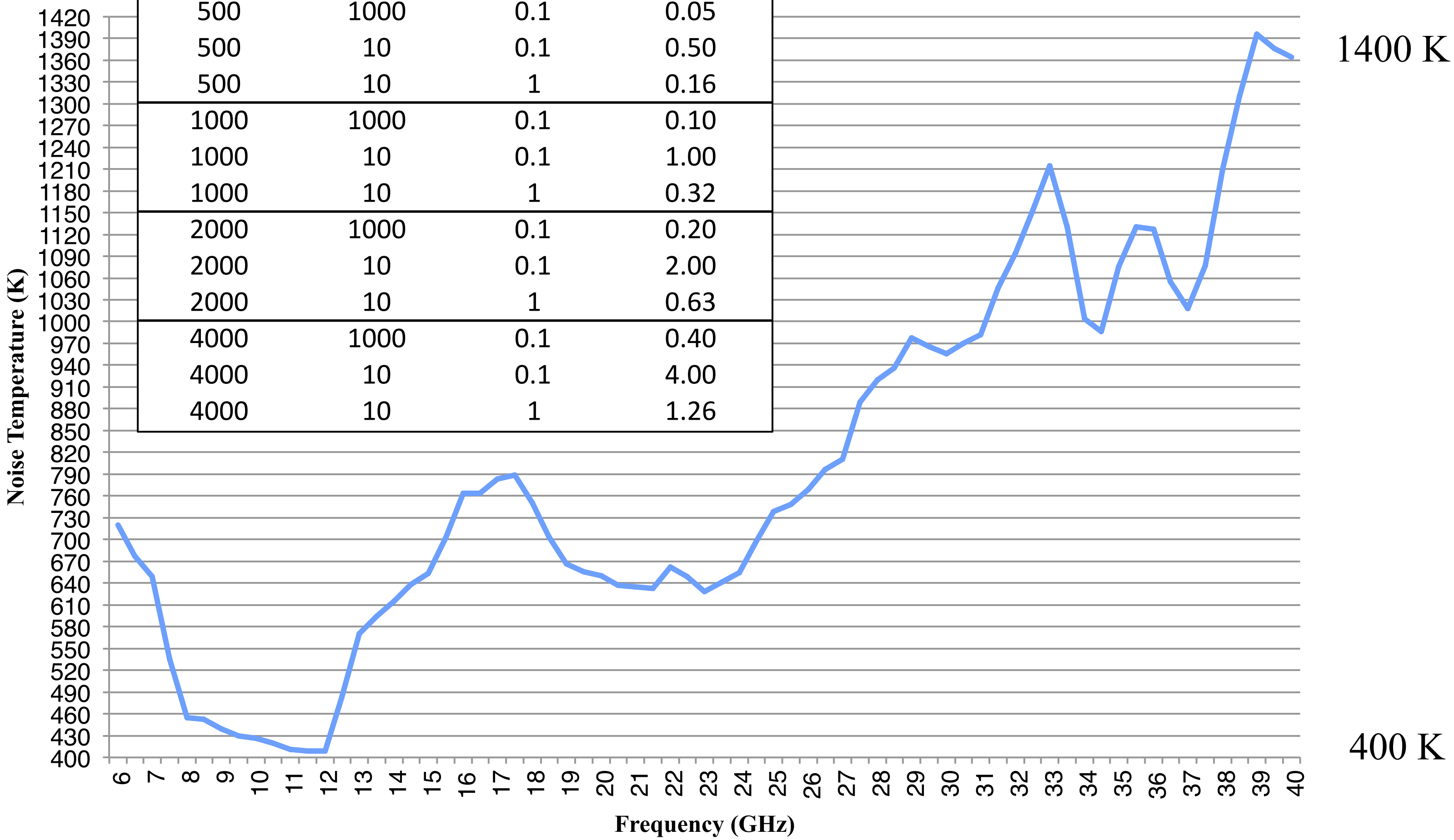
RFE Block Diagram



- Antenna/reference load selector switch
- Couple noise source
- Heterodyne receiver
- Sub-harmonic Image Rejection Mixer
- IF in ADC’s second Nyquist zone (1-2 GHz)
- Control for PLO (amplitude, harmonic)
- Control fir IF: U/LSB and ampllitue

Noise Temperature Analysis

Tsys (K)	B (MHz)	tau (s)	NEDT (K)
500	1000	0.1	0.05
500	10	0.1	0.50
500	10	1	0.16
1000	1000	0.1	0.10
1000	10	0.1	1.00
1000	10	1	0.32
2000	1000	0.1	0.20
2000	10	0.1	2.00
2000	10	1	0.63
4000	1000	0.1	0.40
4000	10	0.1	4.00
4000	10	1	1.26



RFE only. 1 dB of cable/antenna loss adds 200-400 K

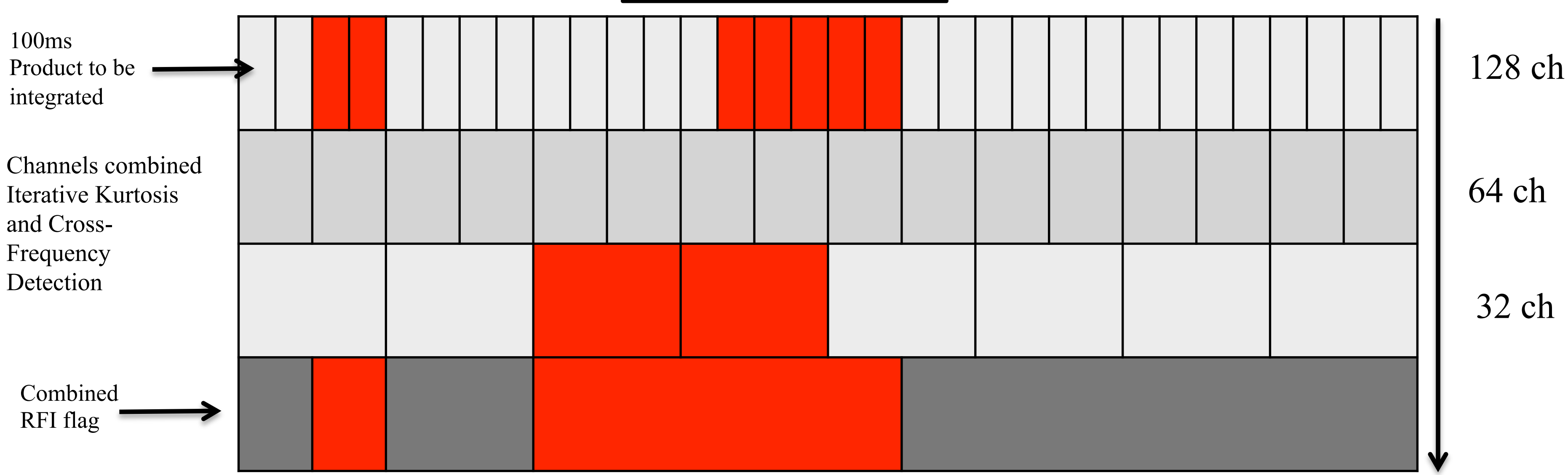
Algorithm Summary

- The design has the following variable parameters –
  - Number of highest resolution channels
  - Integration time
  - Kurtosis threshold
  - CF threshold
  - Windowing used for CF

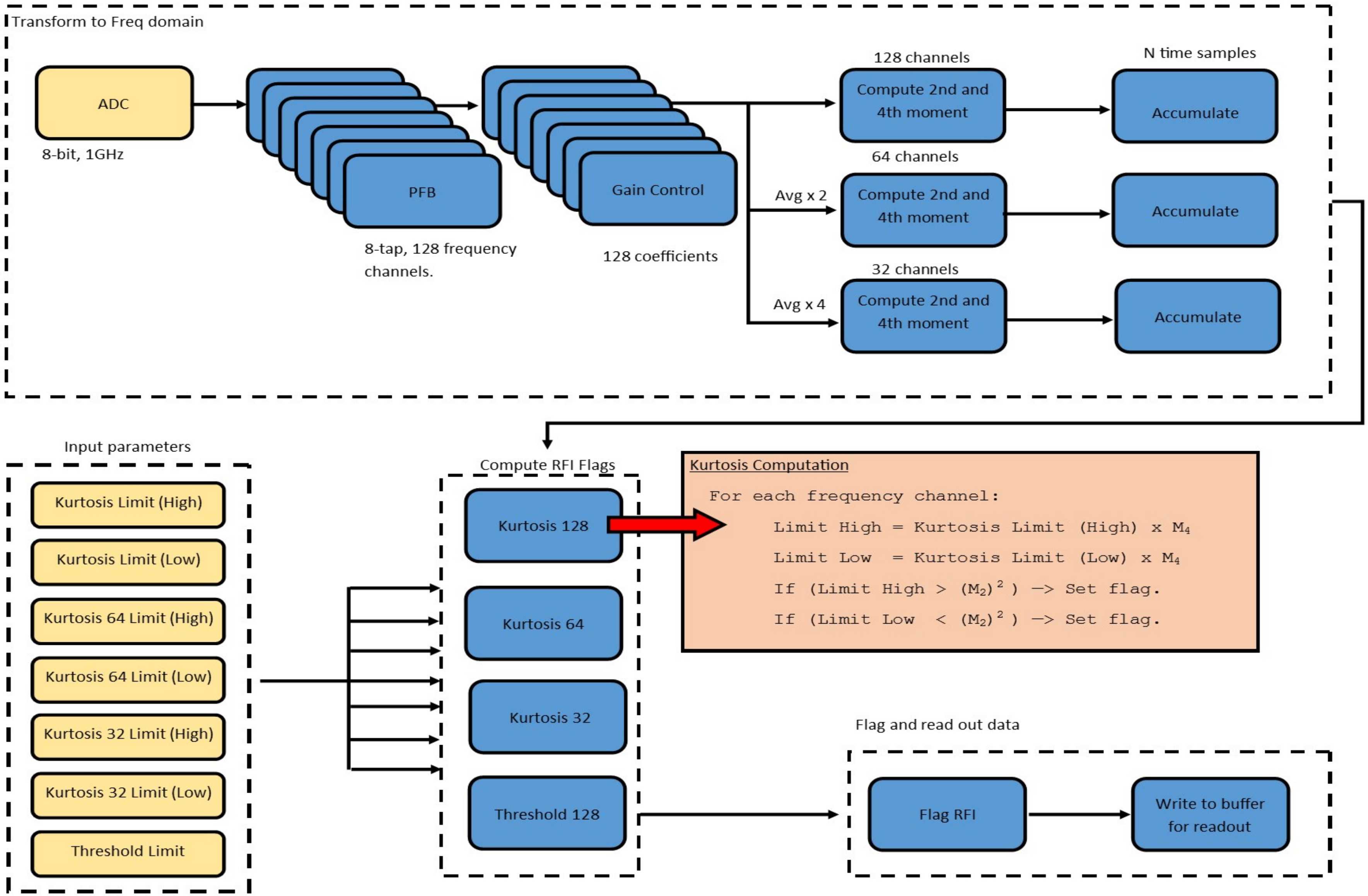
Combined Algorithm

Cross Frequency (128ch/100ms)	**Narrowband signals**
Kurtosis (128-32ch/100ms)	**Pulsed-type/low-level RFI**

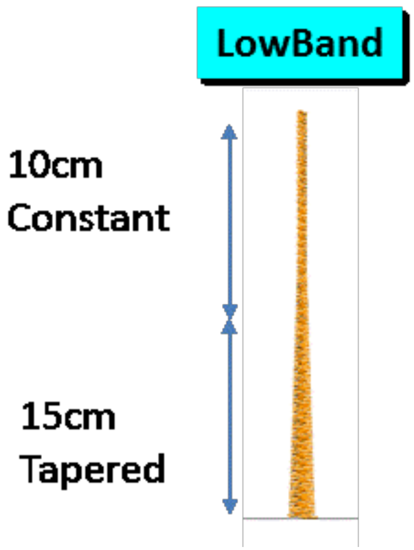
Combined Flags

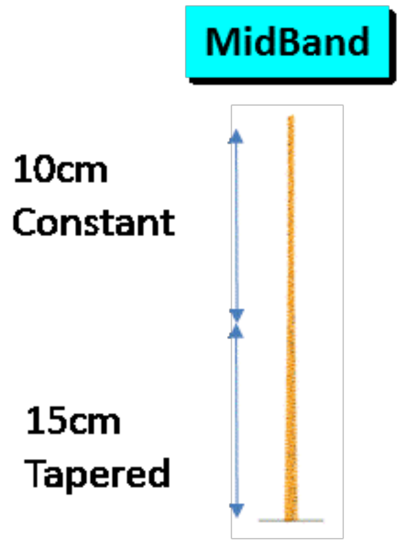


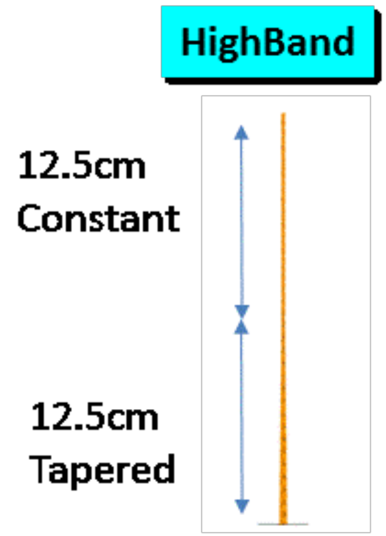
CubeRRT RDB Processor



Preliminary Antenna Design







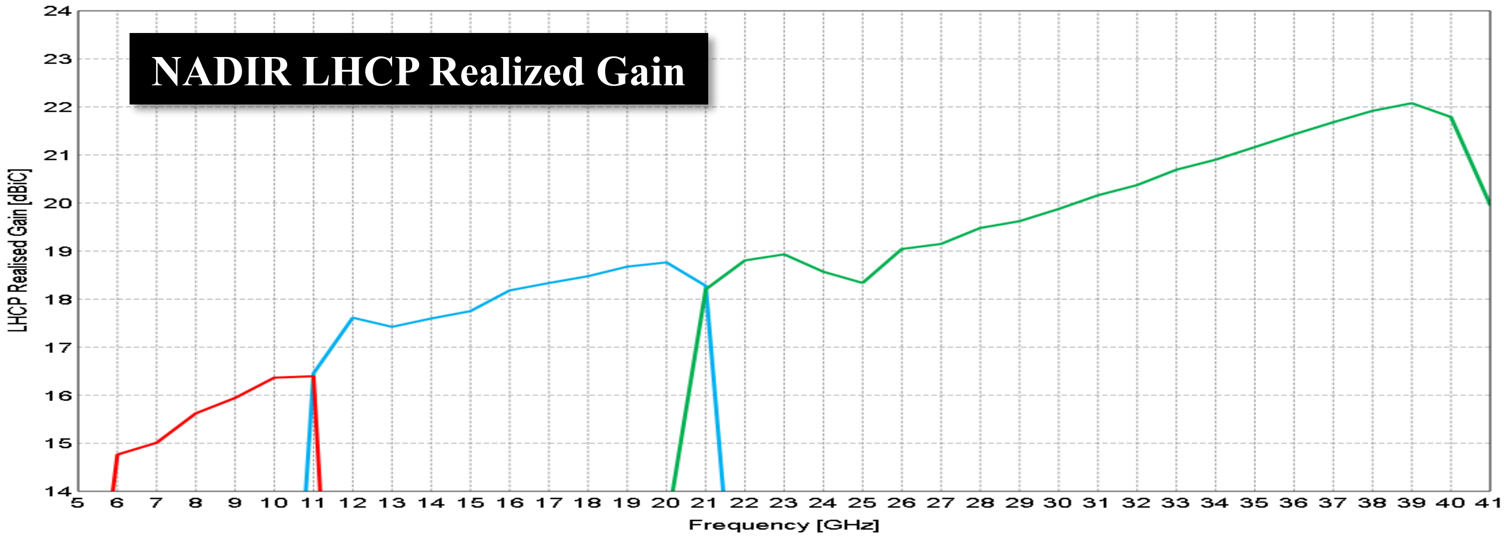
Parameter	Simulation Set & Result
Operation Frequency	6GHz-11GHz
Polarization	LHCP
Realized Gain	14.5-16.2dBiC
Height	25 cm
Impedance	50Ω
Arm Diameter	0.4mm
Bottom Diameter	15.8mm
Top Diameter	6mm
Pitch Distance	2 mm

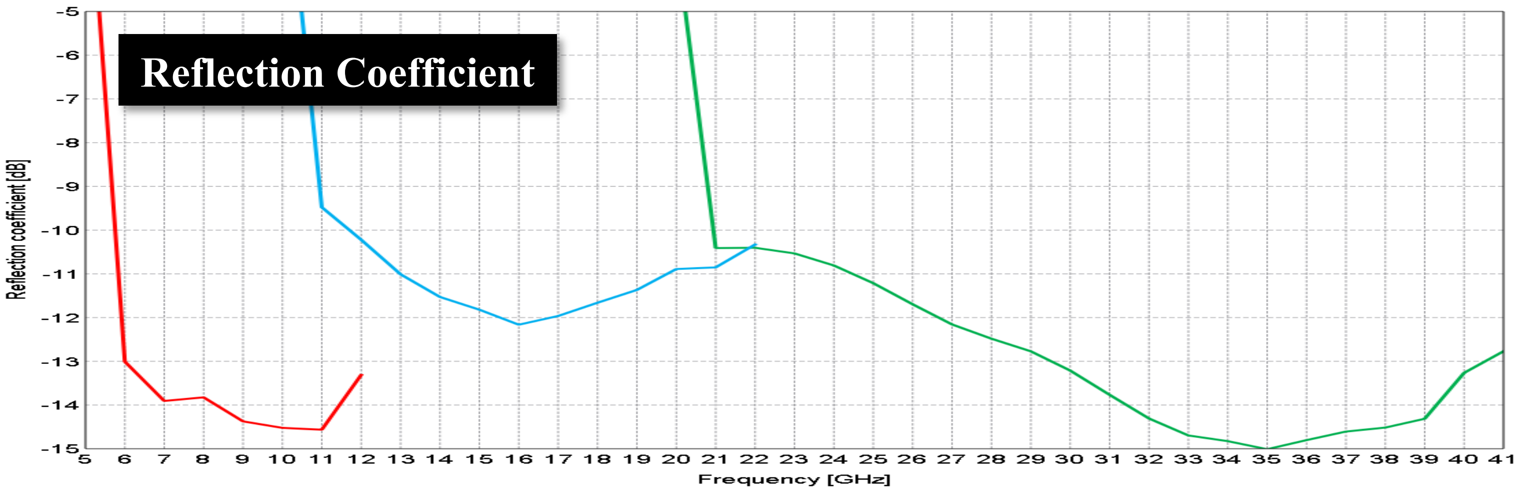
Parameter	Simulation Set & Result
Operation Frequency	11-21GHz
Polarization	LHCP
Realized Gain	16.2-18.5dBiC
Height	25 cm
Impedance	50Ω
Arm Diameter	0.2mm
Bottom Diameter	8.02mm
Top Diameter	3.86mm
Pitch Distance	1 mm

Parameter	Simulation Set & Result
Operation Frequency	21-40GHz
Polarization	LHCP
Realized Gain	18.5-22dBiC
Height	25 cm
Impedance	50Ω
Arm Diameter	0.2mm
Bottom Diameter	4.2mm
Top Diameter	1.8mm
Pitch Distance	1 mm

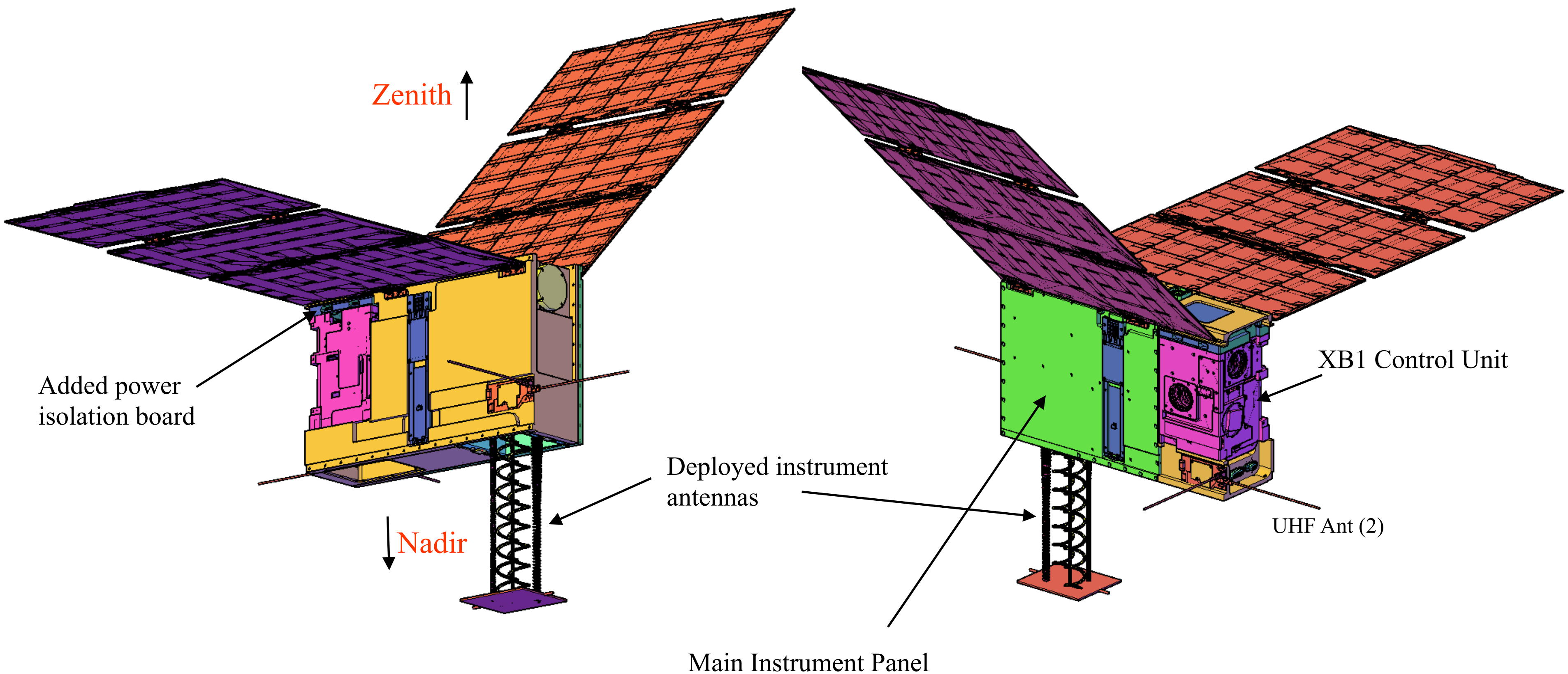
Preliminary Antenna Design

Simulated Antenna Performance

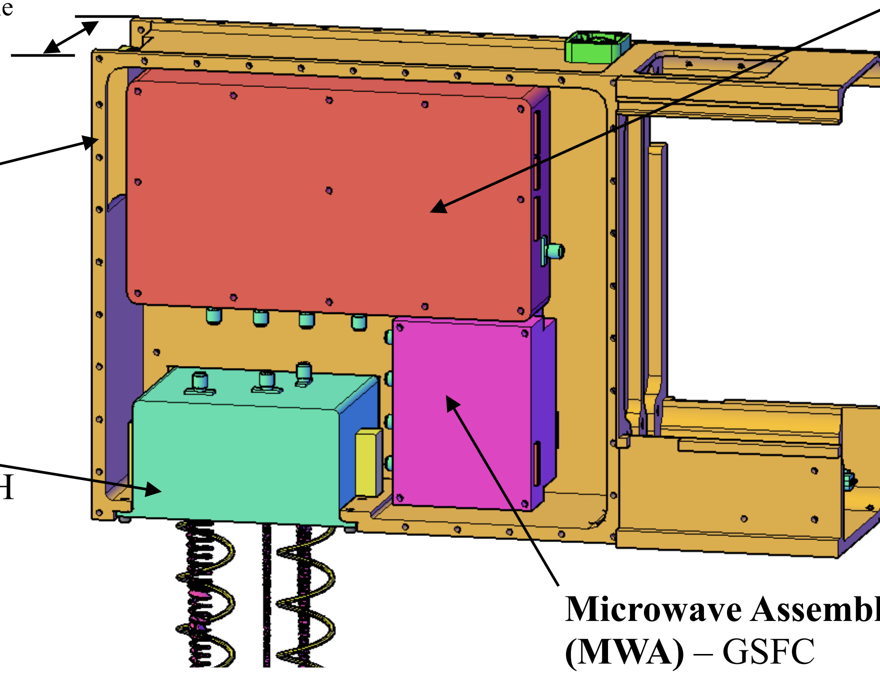




On-Orbit Configuration



Payload Components (1)



3.15" -Available cavity depth

Primary Structure (BCT)

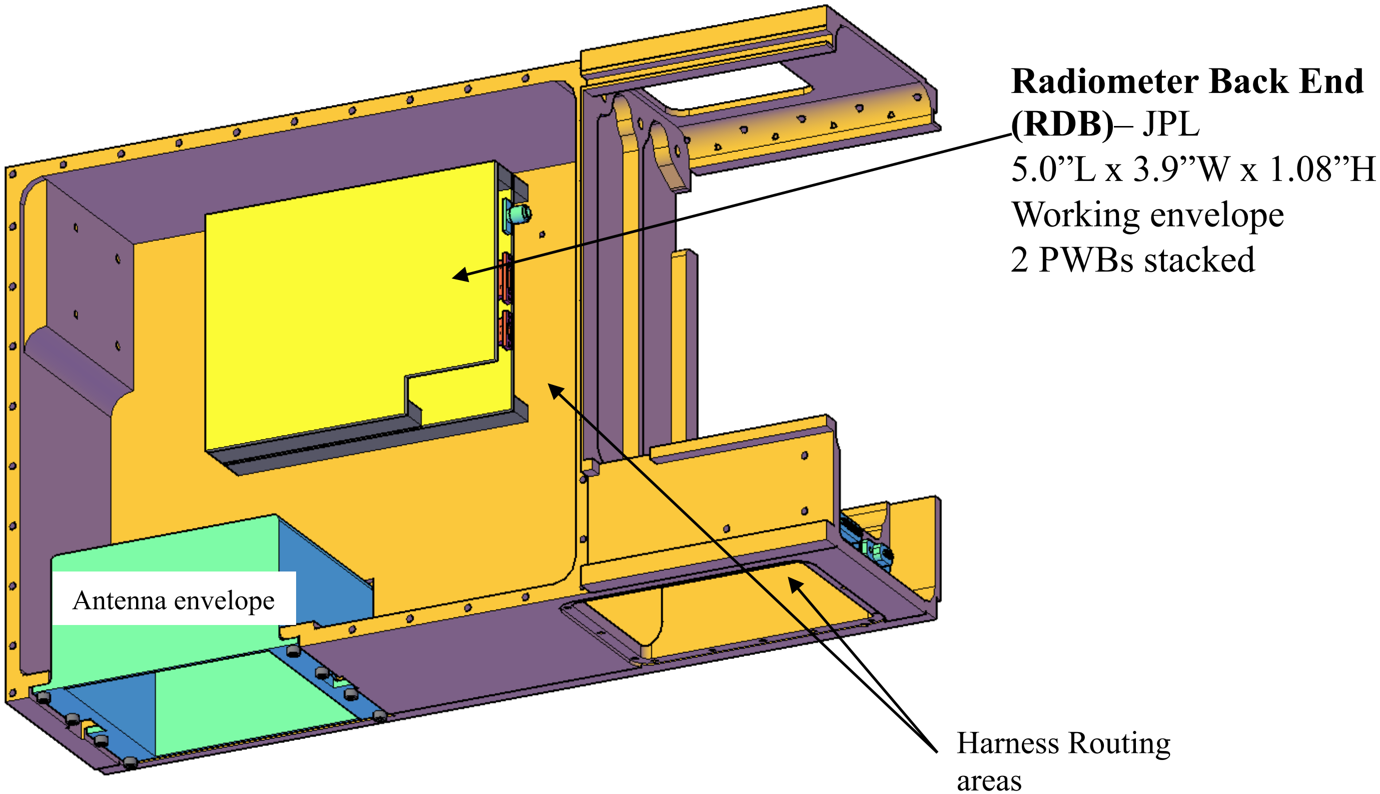
Local Oscillator/ Interm Freq Assy (LOA) – GSFC
7.75"L x 4.25"W x 1.5"H
Working envelope

Antenna (OSU)
3.94"L x 3.25"W x 2.22"H
Working envelope

These 2 units (the Radiometer Front End - RFE) will be integrated on the main instrument panel

Microwave Assembly (MWA) – GSFC
3.5"L x 2.65"W x 2.6" H
Working envelope

Payload Components (2)



Volume and Mass Margins

Item	Size (U)			Mass (kg)		
	Allocation	Estimate	Margin*	Allocation	Estimate	Margin
Payload						
Antenna	0.5	0.38	24%	0.2	0.20	0%
RFE	1	1.06	-6%	1	1.13	-13%
RDB	1	0.13	87%	0.4	0.20	100%
Total	**2.5**	**1.57**	**59%**	**1.6**	**1.53**	**5%**
Spacecraft		2.00	-		9.00	-
Observatory Total	**6**	**3.57**	**41%**	**14**	**10.53**	**25%**

* Margin = (Allocation – Estimate)/Allocation

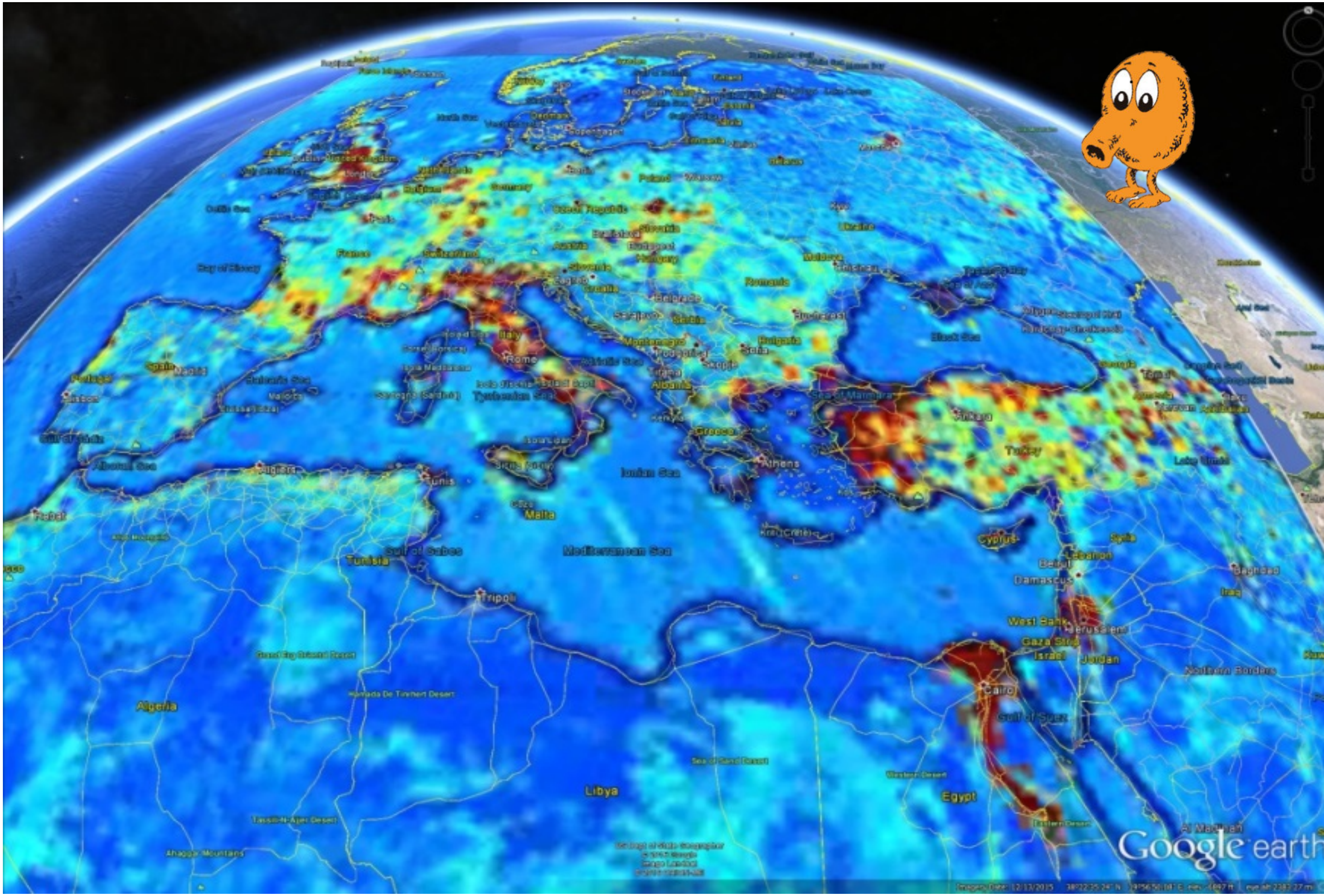
Conops

- Plan to observe at 25% duty cycle to manage battery DoD for 31 W payload
- Emphasize land observations since focus is on scenes containing RFI
- Flexible table-driven tuning of frequency to increase RFI measurements
  - Developing list of known RFI sources from TRMM and JMR observations (nadiral)
  - Large spot size: ~ 10 seconds observation time per footprint
- Mission simulation tool developed to plan weekly observation schedule
  - Algorithms for auto-planning activities under development

Conclusions

- CubeRRT will validate RFI detection and mitigation technologies for future Earth observing microwave radiometers operating 6-40 GHz
- CubeRRT preliminary design completed
- EM development proceeding to payload integration and test in Dec 2016

Questions?



Mediterranean Sea
Ionian Sea
Black Sea
Turkey
Ankara
Greece
Athens
Italy
Rome
Malta
Tunisia
Tunis
Tripoli
Libya
Algeria
Algiers
Egypt
Cairo
Cyprus
Lebanon
Damascus
Jordan
Israel
Romania
Bulgaria
Albania
Google earth