Development of the CubeSat Radiometer Radio Frequency Interference Technology Validation (CubeRRT) Mission System

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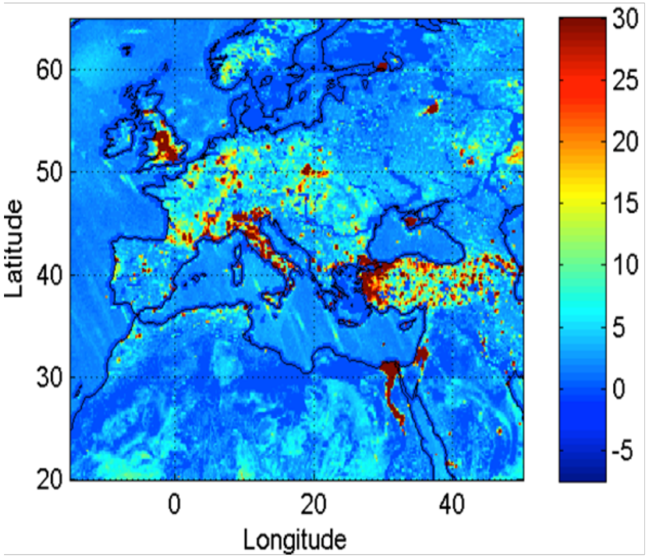
ESTF 2017

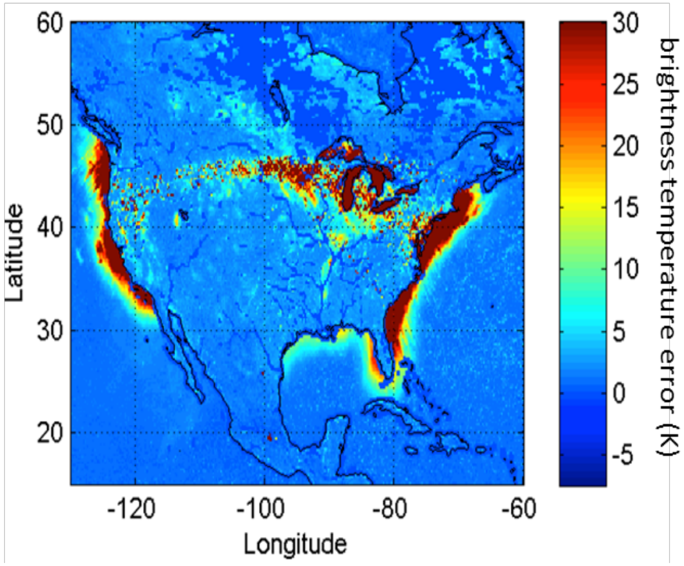
Pasadena, CA

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)
- Radiometers avoid RFI (ideally) by operating in frequency bands where transmission is prohibited, but this is not always possible or effective.

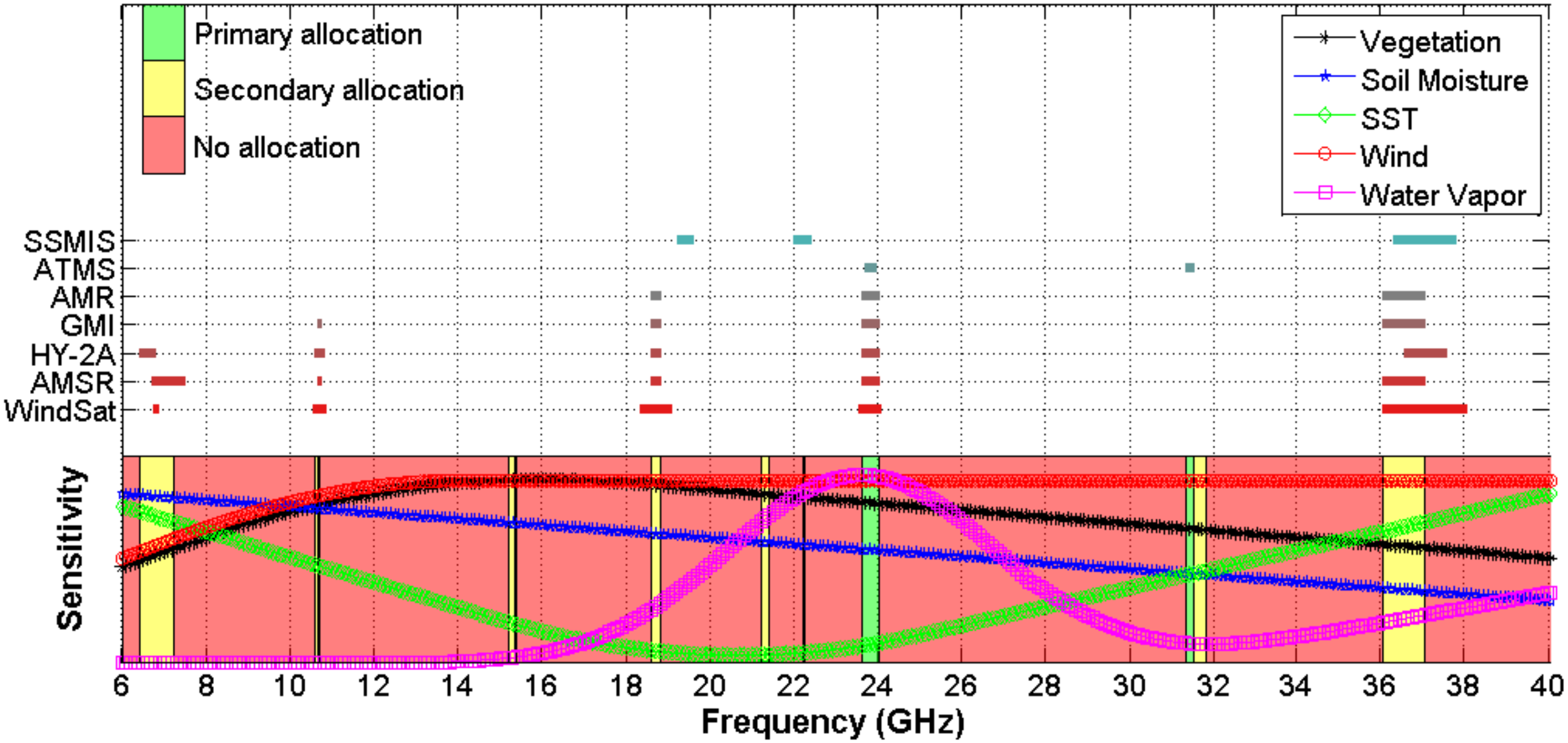
GMI Images at 10.7 (left) and 18.7 (right) GHz showing RFI 'hot spots'





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

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

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

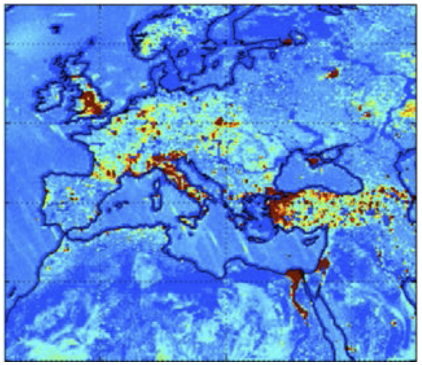
	SMAP	Future
Number of bands	1	6 or more
Bandwidth	20 MHz	100's of MHz in each channel
RFI Processing on ground?	Yes (limited downlink volume)	Not possible (downlink volume too high)
RFI Processing on-board spacecraft?	No; not necessary	Yes; only way to address RFI challenge for future systems

CubeRRT: CubeSat Radiometer Radio Frequency Interference Technology Validation

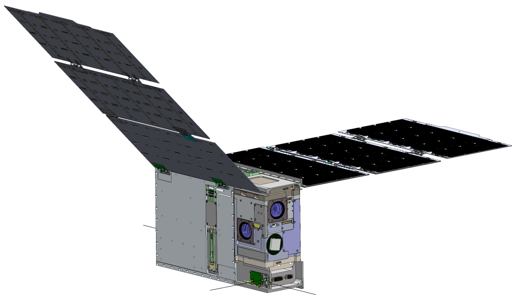
PI: Joel T. Johnson, Ohio State University

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



6U CubeSat layout of CubeRRT components

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	12/16
• Instrument engineering model integration and test	06/17
• Instrument flight model subsystem tests	08/17
• Instrument flight model integration and test	09/17
• Spacecraft integration and test	12/17
• CubeRRT launch readiness	02/18
• On-orbit operations completion	L+12 months

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

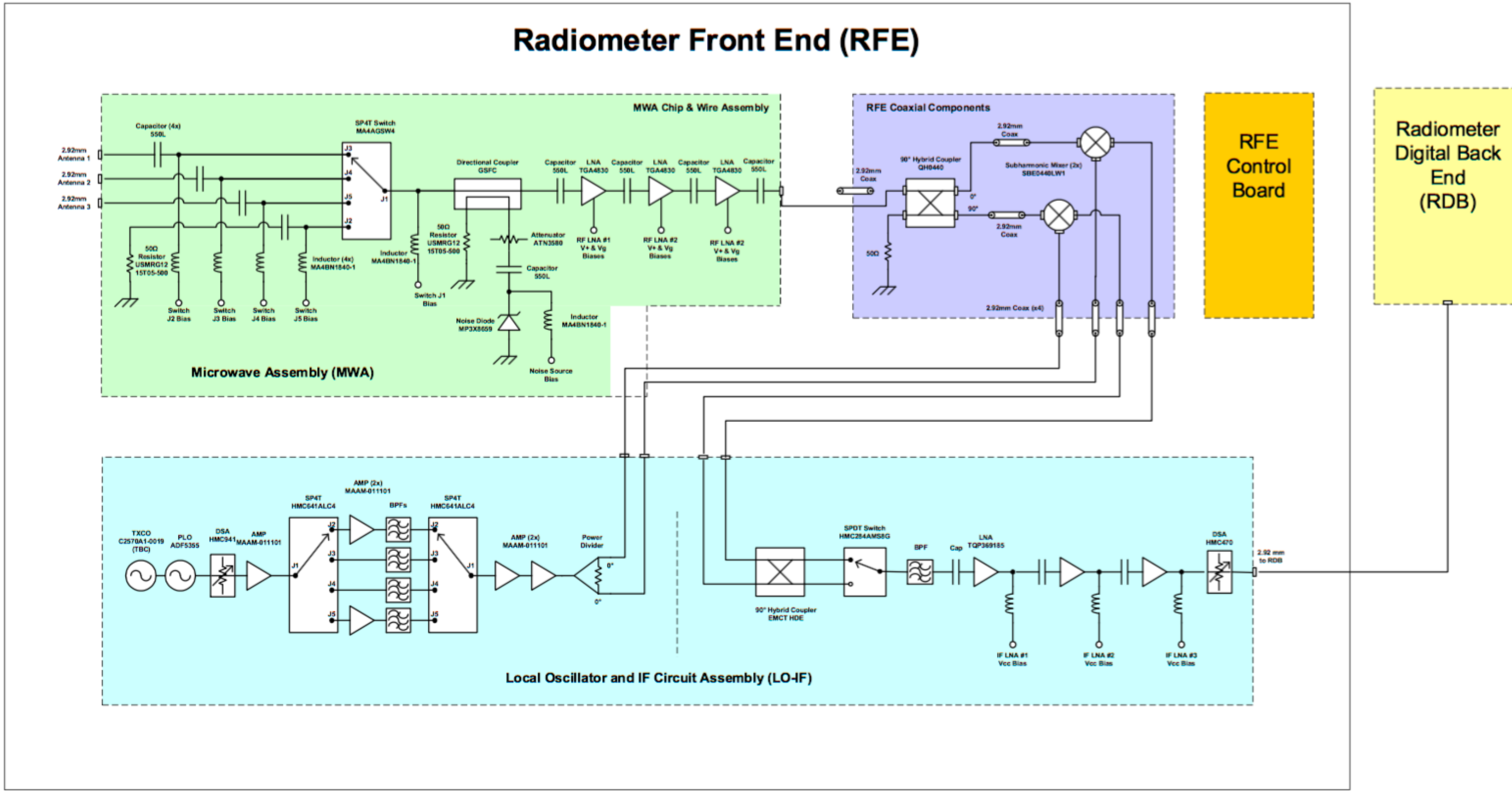
CubeRRT Mission Properties

Frequency	6 to 40 GHz Tunable, 1 GHz instantaneous Operations emphasize nine bands commonly used for microwave radiometry
Polarization	Circular polarization
Observation angle/Orbit (ISS launch)	0° Earth Incidence Angle 400 km altitude, 51.6° orbit inclination
Spatial Resolution	80 km (40 GHz) to 240 km (6 GHz)
Integration time	100 msec
Ant Gain/Beamwidth	12dBi/30° (6 GHz), 21 dBi/10° (40 GHz)
Interference Mitigation	On-board Nyquist sampling of 1 GHz spectrum; On-board real-time Kurtosis 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

Schedule Status

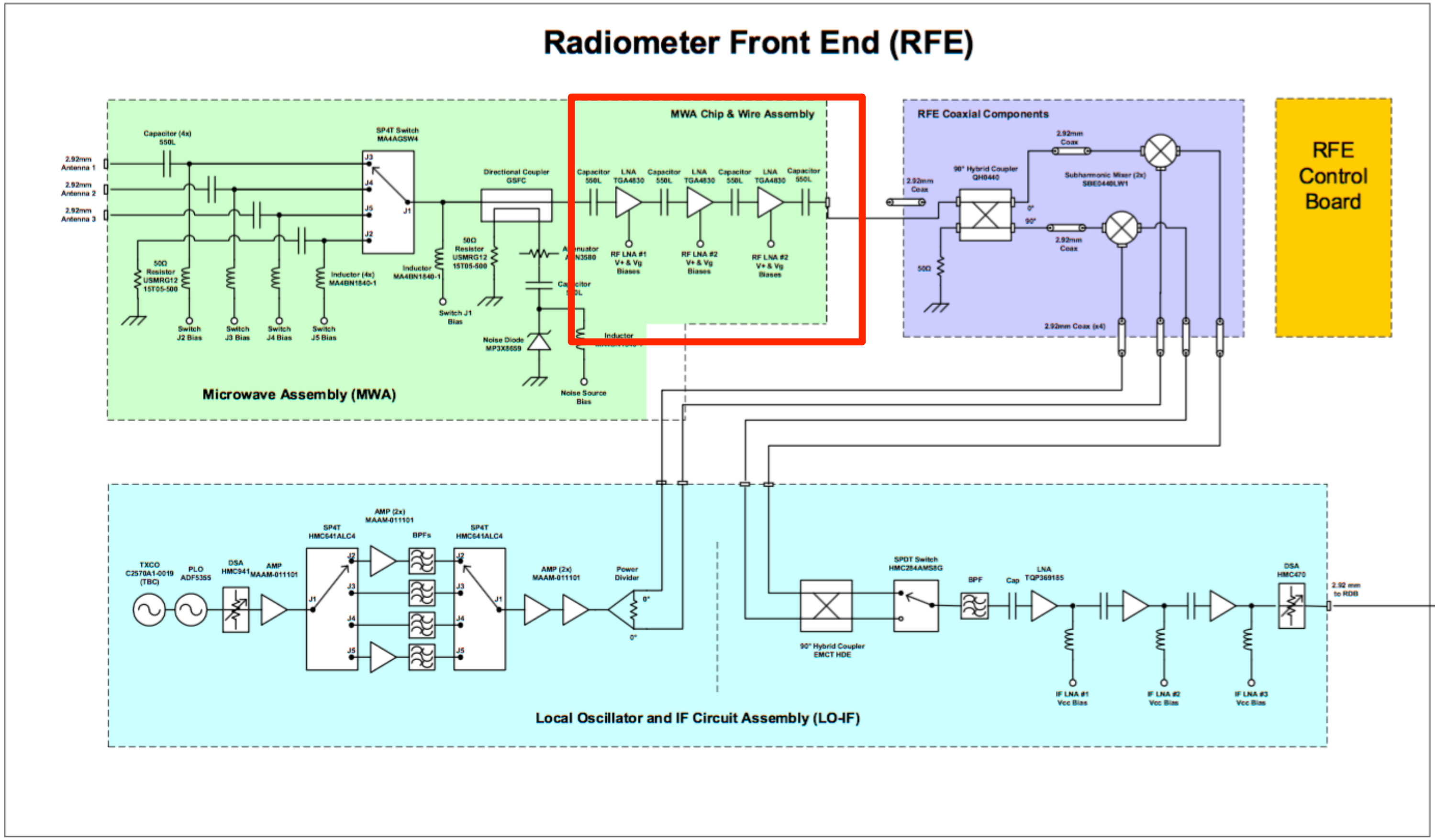
- Three primary payload subsystems
  - Radiometer Front End (RFE); developed by NASA GSFC
  - Radiometer Digital Backend (RDB); developed by NASA JPL
  - CubeRRT Antenna (ANT); developed by OSU
- EM payload I&T continues through June 2017
  - Parallel to FM payload hardware development
  - Focus on interfaces (RDB-RFE, RDB-S/C)
  - Ops rehearsal activities with EM planned for summer 2017
- FM development already initiated
  - FM payload delivery for S/C integration scheduled for 9/30
- Integrated S/C delivery due February 2018
  - Launch Q2 2018 on ELaNA 23

CubeRRT RFE Block Diagram



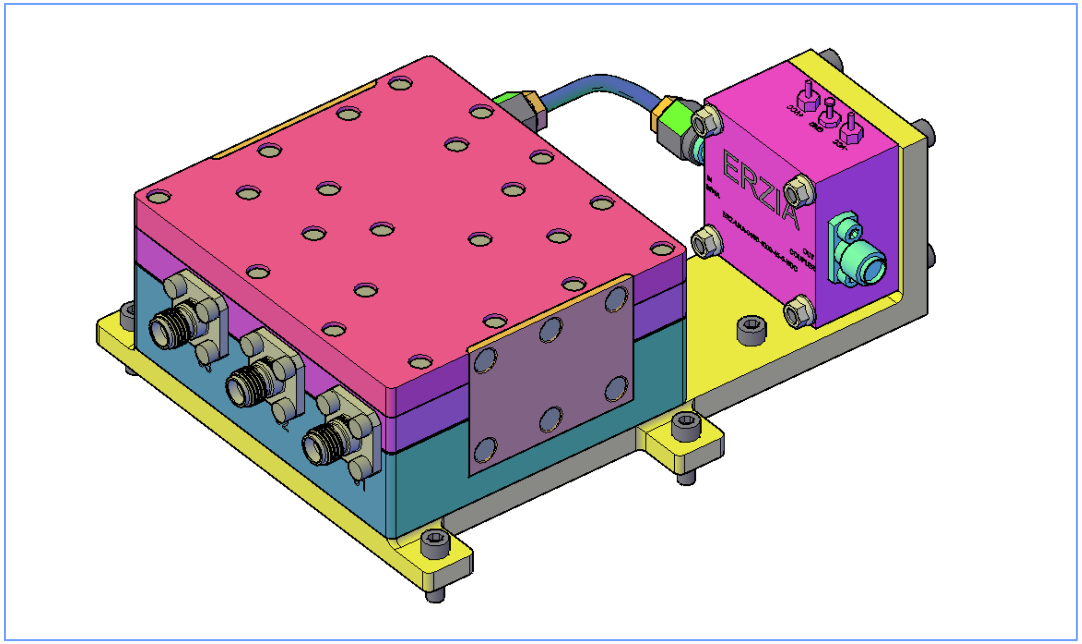
- RFE: Provide radiometric calibration sources, amplification, tunable down-conversion, and band definition for digital backend

CubeRRT RFE Block Diagram

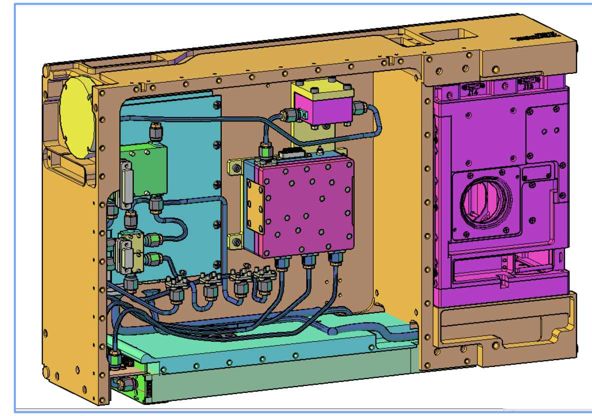


- EM tests resulted in revised design using coaxial LNA for FM

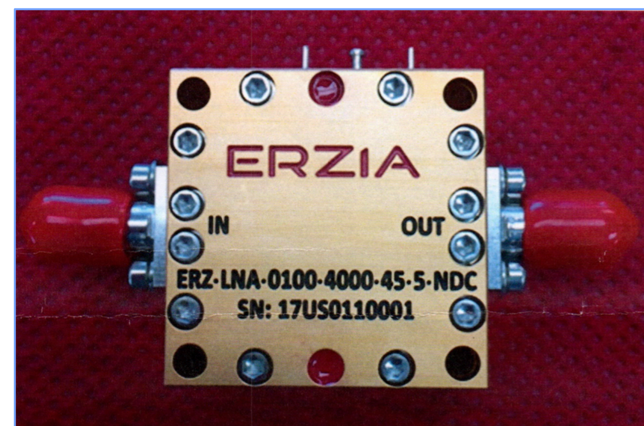
FM Microwave Assembly (MWA)



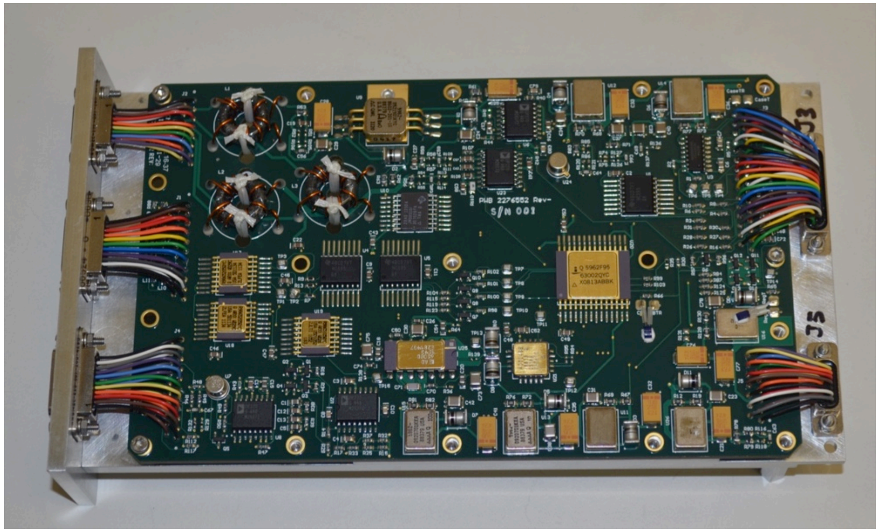
FM Microwave Assembly (MWA)



CubeRRT Payload with Revised FM MWA

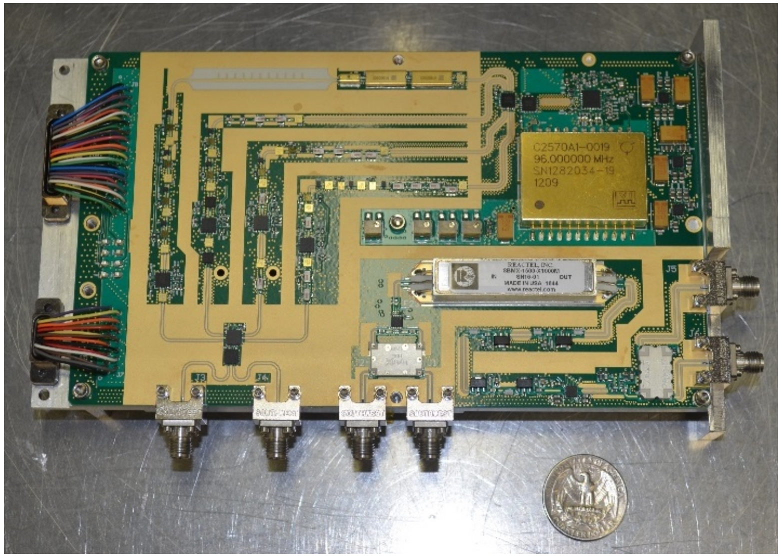


Erzia CubeRRT 40 GHz Coaxial LNA SN01



ProtoFlight RFE Control Board

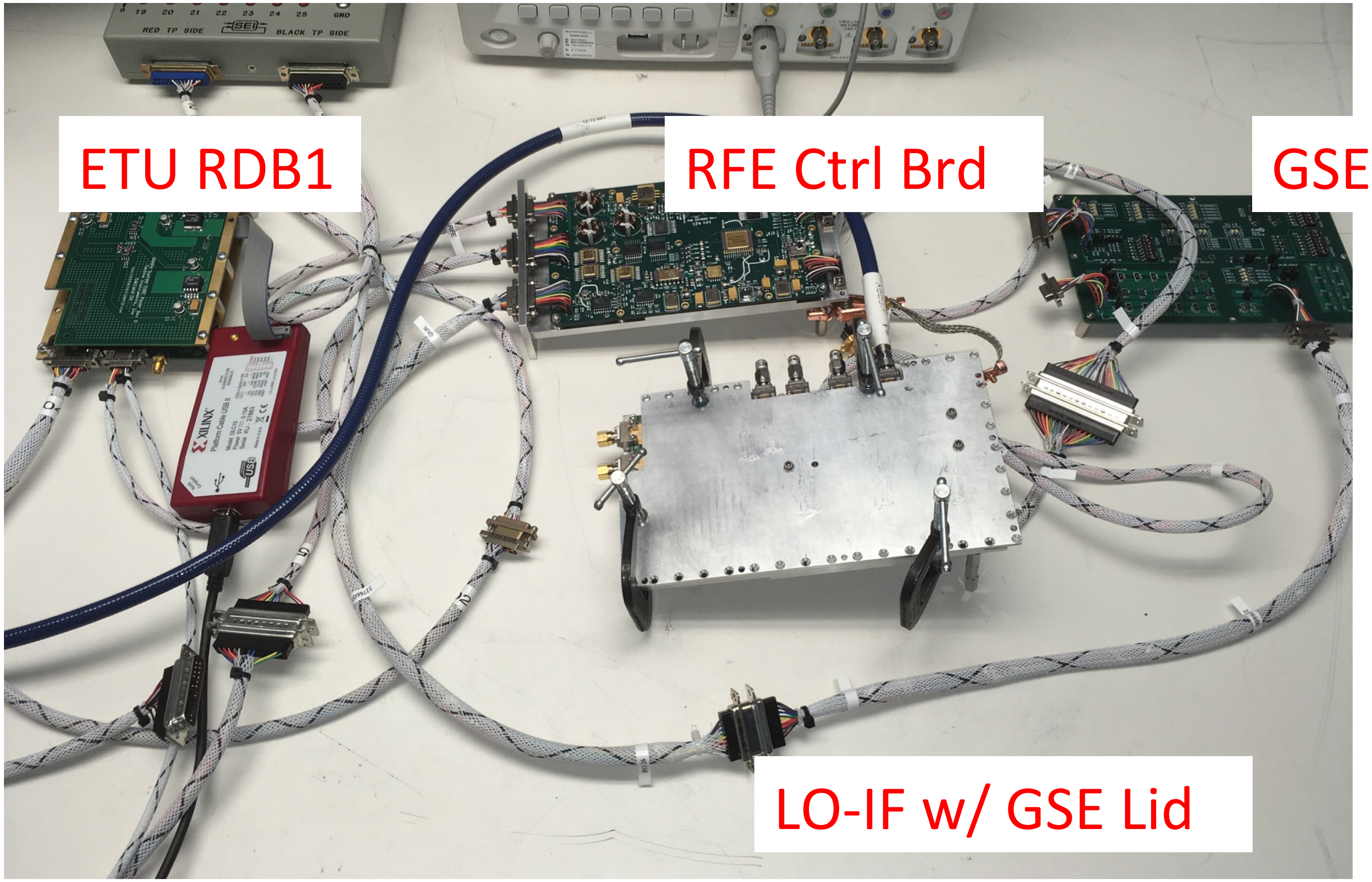
- EM Control Board tested – meets reqs.
- EM will be used for FM



EM LO-IF RF Board

- FM LO-IF RF Board revised layout now in process

EM RFE I&T - Underway



Radiometer Digital Backend (RDB) Processor

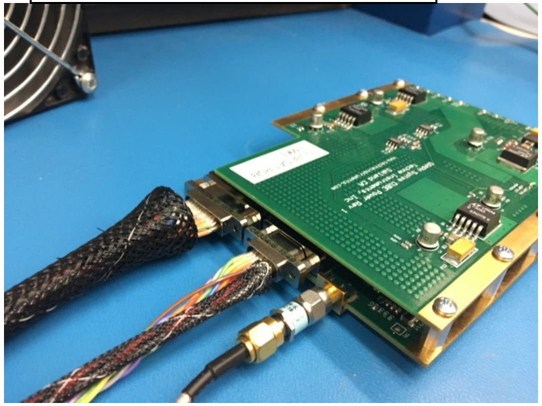
- Samples 1 GHz IF bandwidth at 2 GSPS and performs RFI detection
- Concurrent implementation of algorithms chosen

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

- Multiple algorithms offer better performance for differing RFI types
- Detection and filtering performed using a combination of firmware (Zynq FPGA fabric) and software (Zynq embedded ARM processor)
- Provides options in trading off power consumption versus flexibility and processor speed
- Four RDB ETU's developed:
  - ETU1 and 2 identical; one used for system development at JPL, second as GSE at GSFC
  - ETU3 implemented to address issue in ETU1/2 with onboard Flash for Zynq programming
  - ETU4 implemented to substitute smaller capacity Zynq chip to reduce power consumption
- ETU RDB interfaced to spacecraft XB1 emulator
- Integration with RFE currently in process

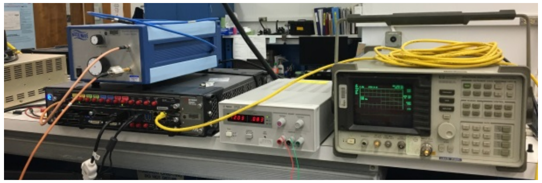
Payload – RDB test setup

RDB unit – ETU 2

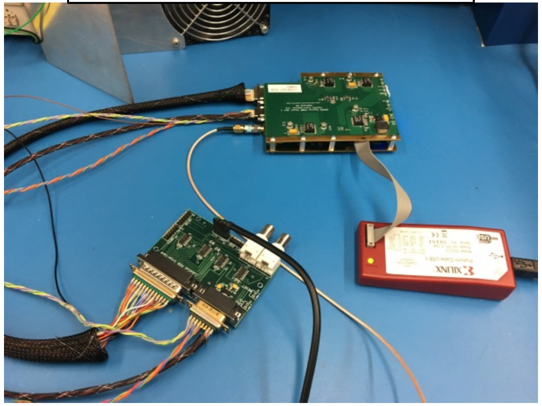


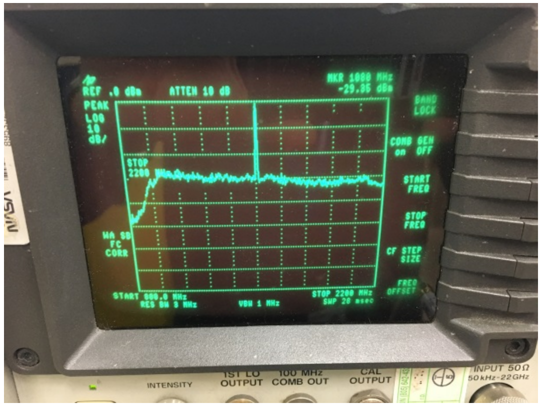
Arbitrary Waveform Generator

AWG Test Setup



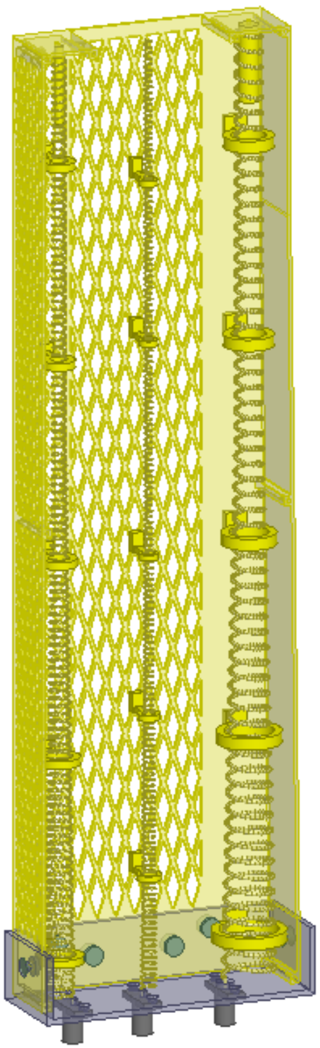
RDB unit+Interface



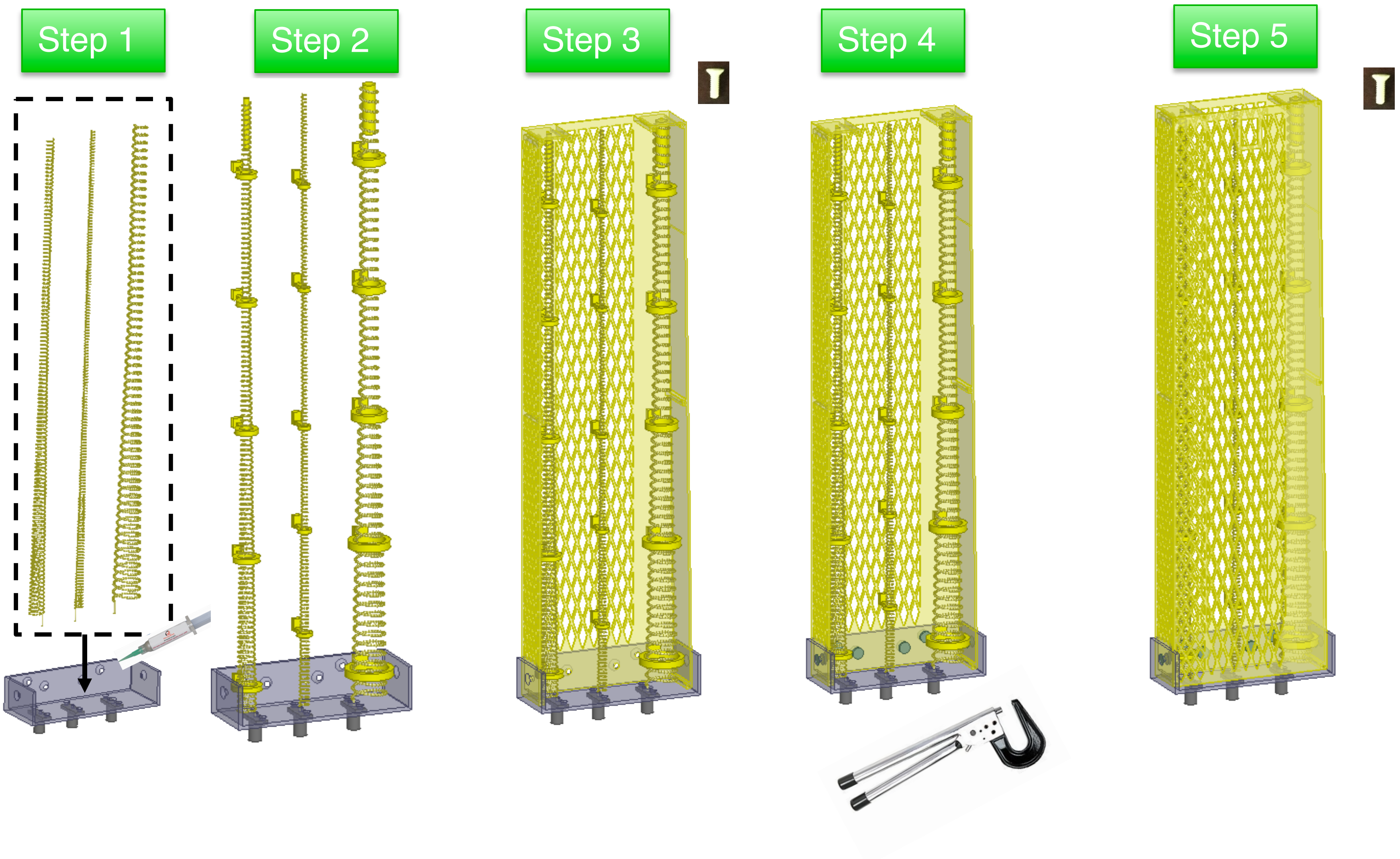


Antenna

- Three tapered helical antenna elements to allow coverage of 6-40 GHz
- Antenna selected for appropriate CubeRRT tuning frequency
- Radome included to support antennas and to improve tuning
- Radome design optimized for each antenna element
- Antenna EM near complete for performance and deployment testing
- FM identical to EM with exception of gold plating of antenna elements



Antenna Detail and Assembly



Antenna System Overall Performance

Frequency	S-parameter [dB] (s11,s22,s33,s21,s31,s32)	Boresight Gain [dBiC]	Cross Track		Along Track	
			HPBW Degree)	SLL (dB)	HPBW (Degree)	SLL (dB)
6.8GHz (Antenna 1)	**(-10,-1.9,-2.6,-55,-35,-43)**	13.4	31	12	37	15
10.8GHz (Antenna 1)	**(-13, -3.4,-1.4,-49,-46,-45)**	17	22	13	24	12
18.7GHz (Antenna 2)	**(-14, -14,-4.7,-45,-46,-39)**	19	16	15	17	15
19.4GHz (Antenna 2)	**(-14, -15,-3.7,-46,-48,-45)**	19	17	14	16	12
22.2GHz (Antenna 2)	**(-16, -15,-14,-34,-34,-46)**	19	14	8	16	11
23.8GHz (Antenna 3)	**(-9,-19,-14,-42,-46,-33)**	19	17	14	20	16
31.4GHz (Antenna 3)	**(-7.5,-15,-16,-34,-34,-48)**	18	23	14	20	15
34GHz (Antenna 3)	**(-8,-13,-18,-34,-34,-48)**	20	21	16.5	18	12.5
36.5GHz (Antenna 3)	**(-10,-15,-20,-45,-33,-48)**	21	12.5	17	13	14
37.5GHz (Antenna 3)	**(-7,-16,-19,-34,-40,-37)**	21	12	17	13	15

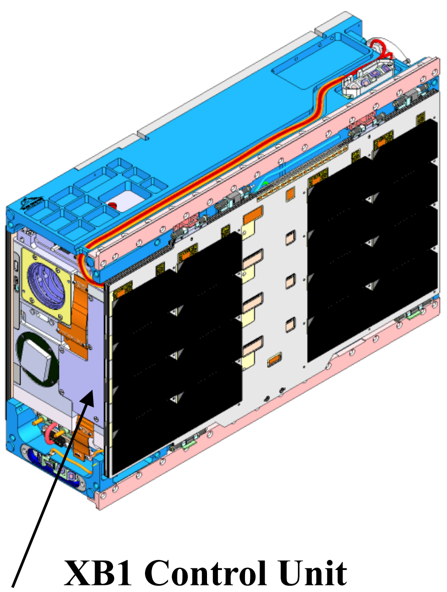
CubeRRT Spacecraft

- CubeRRT 6U bus provided by Blue Canyon Technologies, Inc.
- XB1 unit provides flight computer, attitude control, navigation information, and communications
- One contact/ weekday planned using WFF ground station

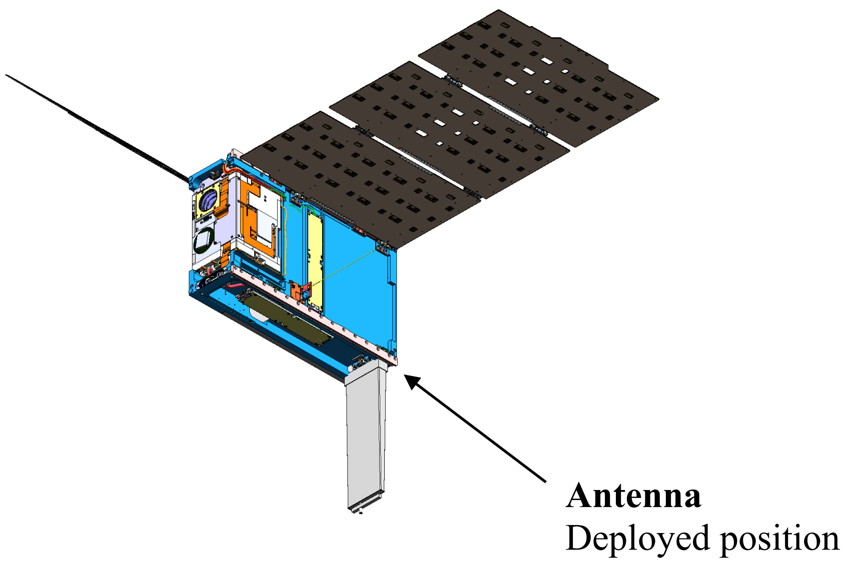
Antenna Deployment

- CubeRRT operates in a nadir viewing configuration
- Antennas deploy from stowed position post-launch
- Circularly polarized antenna design allows for yaw-steering in science mode to improve power budget

Post-deploy stowed



Payload antennas deploy toward nadir

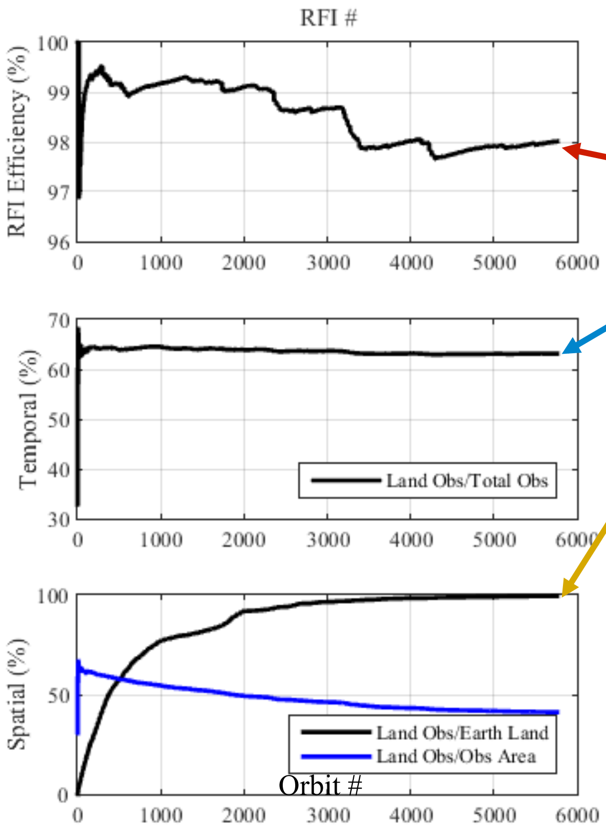


On-Orbit Operations

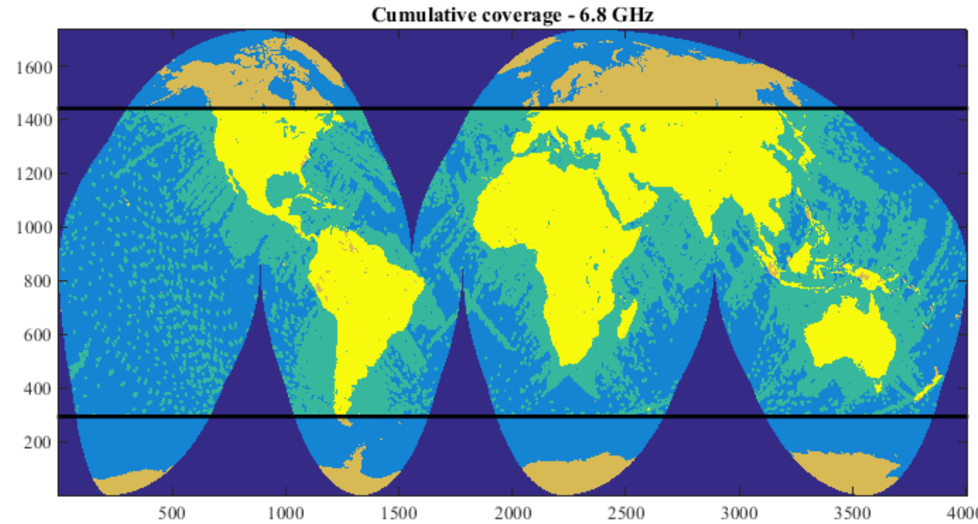
- Plan to operate up to 33% duty cycle (~30 minutes out of a ~90 minute orbit) to manage battery depth-of-discharge for 30 W payload
- Emphasize land observations since focus is on scenes containing RFI
  - Large spot size: ~ 10 seconds observation time per location
- Payload powered off over South Atlantic Anomaly to reduce risk of damage
- Flexible table-driven tuning of frequency to increase RFI measurements
- Mission simulation tool developed to plan weekly observation schedule
  - ICD between BCT and OSU developed to coordinate process

CONOPS: 1 Year Results

- 1 year of operation operating 30 min/orbit and frequency switching every 10s results in:



- Baseline mission objectives (10 hours of operation in all 10 frequency bands) achieved within first 14 days
- Average RFI efficiency of 98%
- 65% of total observation time over land
- Over 99% of land observed at each frequency



Conclusions

- CubeRRT will validate RFI detection and mitigation technologies for future Earth observing microwave radiometers operating 6-40 GHz
- CubeRRT EM and FM development in process
- Payload FM delivery for spacecraft integration: 9/30/17
- Integrated observatory delivery to Nanoracks: 2/1/18

ESTO Earth Science Technology Office

Questions?