DEVELOPMENT OF THE CUBESAT RADIOMETER RADIO FREQUENCY INTERFERENCE TECHNOLOGY VALIDATION (CUBERRT) SYSTEM

Christopher Ball, Chi-Chih Chen, Andrew O'Brien, Graeme Smith, Christa McKelvey, Mark Andrews, J. Landon Garry, Joel Johnson
Department of Electrical and Computer Engineering and ElectroScience Laboratory,
The Ohio State University, Columbus, OH

Sidharth Misra, Shannon Brown, Robert Jarnot
NASA Jet Propulsion Laboratory, Pasadena, CA

Jonathan Kocz
California Institute of Technology, Pasadena, CA

Damon Bradley, Priscilla Mohammed, Jared Lucey, Kevin Horgan, Quenton Bonds, Carlos Duran-Aviles, Michael Solly, Jeffrey Piepmeier
NASA Goddard Space Flight Center, Greenbelt, MD

Matthew Pallas, Ervin Krauss
Blue Canyon Technologies, Boulder, CO

ABSTRACT

The CubeSat Radiometer Radio Frequency Interference Technology Validation (CubeRRT) mission is developing a 6U CubeSat system to demonstrate radio frequency interference (RFI) detection and filtering technologies for future microwave radiometer remote sensing missions. CubeRRT will perform observations of Earth brightness temperatures from 6-40 GHz using a 1 GHz bandwidth tuned channel and will demonstrate on-board real-time RFIS processing. The system is currently under development, with an expected launch date in mid-2018 followed by a one year period of on-orbit operations. Development of the CubeRRT spacecraft, radiometer instrument, and concepts of operation are described in this paper.

Index Terms— Microwave radiometry, radio frequency interference, CubeSat

1. INTRODUCTION

Recent passive microwave measurements below 40 GHz have shown an increase in anthropogenic interference [1]-[2], corrupting geophysical retrievals in a variety of crucial science products, including soil moisture, atmospheric water vapor, sea surface temperature, sea surface winds, and many others. Spectrum for commercial use is becoming increasingly crowded, accelerating demand to open the bands reserved for passive microwave Earth observation and radio astronomy applications to general use. Due to current shared spectrum allocations, microwave radiometers must co-exist with terrestrial RFI sources, often resulting in RFI corruption as demonstrated in numerous past missions. As active sources expand over larger areas and occupy additional spectrum, it will be increasingly difficult to perform radiometry without an RFI filtering capability. Co-existence in some cases should be possible provided that a subsystem for filtering of RFI is included in future systems.

Initial progress in RFI filtering technologies for microwave radiometry in space has been achieved in the SMAP [3]-[5] mission. The SMAP radiometer utilizes a digital subsystem that operates on a 24 MHz bandwidth, centered at the protected 1413 MHz frequency allocation. Digital subsystems for higher frequency microwave radiometry over the 6-40 GHz range require a larger bandwidth, so the bandwidth, processing power, and on-board operation capabilities for RFI filtering must also increase accordingly. While the SMAP mission is demonstrating RFI filtering in a single 24 MHz channel, all RFI processing is performed on the ground following downlink of high data rate products such as a spectrogram of the received signal and its kurtosis. The multiple channels and much larger bandwidths of current and future radiometer missions operating 6-40 GHz do not allow downlink of this data volume to occur, so that RFI processing on the ground is not possible. Real-time, on-board RFI processing is therefore an important technology needed for future missions.

To demonstrate on-board, real-time RFI processing from 6-40 GHz, the CubeRRT mission was selected under NASA's In-space Validation of Earth Science Technologies (InVEST) program [6]. This talk focuses on the development of the CubeRRT spacecraft and payload instrument with discussion of projected on-orbit operations. The CubeRRT satellite is currently scheduled for February 2018 delivery in anticipation of a mid-2018 launch.

2. MISSION OBJECTIVES

The CubeRRT radiometer will be designed to make wideband measurements in ten distinct bands relevant to passive microwave remote sensing in the range of 6 GHz to 40 GHz. The RFI mitigation technology will be demonstrated on flight-ready hardware to advance to Technology Readiness Level (TRL) 6 prior to launch and on a spaceborne CubeSat platform to advance from TRL 6 to 7. The CubeRRT mission intends to quantify the capability of the wideband digital RFI filtering technology to detect and remove pulsed and continuous sinusoidal RFI with a power level of 2 times the noise equivalent delta temperature (NEDT) or greater for a 1GHz Nyquist bandwidth. The baseline CubeRRT mission will provide radiometry data from at least 100 hours of spaceborne operation, including at least 10 hours of spaceborne operation in each of ten common radiometry bands.

3. CUBESAT SYSTEM

The CubeRRT 6U spacecraft bus is being designed, constructed, and tested by Blue Canyon Technologies (BCT). Fig. 1 shows a concept drawing of CubeRRT in its deployed configuration. Key features of the spacecraft include the bus power system (solar panels, batteries), an isolated instrument power supply to mitigate ground loops in the radiometer payload, data communications systems (Cadet radio and Globalstar satellite communications), the mechanical frame, and other avionics components.

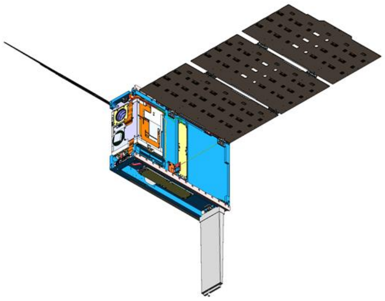

Figure 1. 3D rendering of the CubeRRT system in orbit deployed configuration

4. PAYLOAD INSTRUMENT

The CubeRRT payload consists of 3 subsystems: a set of wideband tapered helical antennas, a tunable analog radiometer subsystem, and a digital backend performing real-time RFI detection and filtering in a 1 GHz bandwidth.

4.1. Radiometer Front-End

The tunable analog radiometer front-end (RFE) subsystem is being developed by NASA Goddard Space Flight Center (GSFC). The RFE covers 6-40 GHz with a single tunable superheterodyne receiver and internal calibration. This architecture was chosen to meet the Size Weight and Power (SWaP) constraints of the 6U platform. The RFE is internally calibrated using a reference load and coupled wideband noise source. The input to the RFE is chosen using a four-position switch to select from one of three antennas and reference load. Wideband LNAs provide pre-amplification. The compact architecture of the front-end does come at a cost of noise figure and image rejection ratio, but predicted performance is sufficient to meet the technology demonstration goals. A photograph of the RFE's Microwave Assembly (MWA) (featuring the switch, internal calibration sources and LNAs) is shown in Fig. 2.

Frequency tuning is accomplished with a tunable phase-locked oscillator (PLO) and a subharmonic image rejection (IR) mixer. While a more advanced architecture such as an up-down converter typical of spectrum analyzers could be used, the simplicity of the IR mixer is a good match for the system SWaP allocations. An advantage of the IR mixer topology is the ability to select between the upper and lower sidebands using a switch in the intermediate frequency (IF) circuit. This flexibility enables complete spectral coverage between 6 and 40 GHz in 50 MHz steps producing a 1 GHz wide IF passband. Amplitude equalization across the RF tuning range is accomplished with a digital step attenuator to ensure the desired power level is available to the ADC converter in the digital back-end.

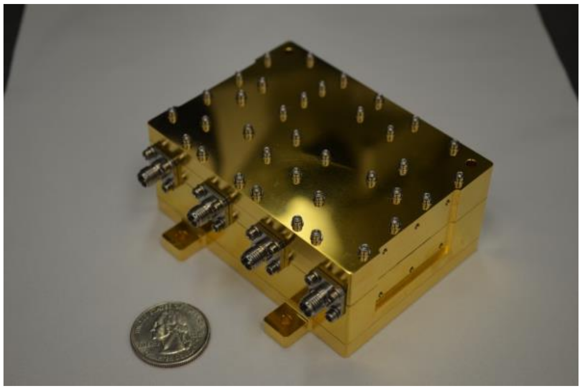

Figure 2. Prototype CubeRRT RFE MWA showing four connectors for the three antenna inputs and RF output

4.2. Radiometer Digital Back-End

The radiometer digital back-end (RDB) subsystem is being developed by NASA Jet Propulsion Laboratory (JPL). The RDB consists of two main components: an ADC capable of digitizing a 1GHz bandwidth, and an FPGA for RFI processing. Fig. 3 shows the RDB engineering test unit delivered to GSFC for integration. The FPGA receives the digitized data and performs several stages of processing. Initially the data is transformed into a frequency spectrum using a polyphase filterbank. The associated channels can then be passband compensated using a set of coefficients defined and updated by the user.

Figure 3. RDB engineering test unit (5” wide, 3.9” deep) with power board above and FPGA board below

The presence of RFI is determined for each frequency channel. Two methods of detection are used: 1) a simple threshold detection algorithm where the power in each channel is compared to a channel-specific threshold 2) a kurtosis test for each channel. If either value deviates beyond an expected threshold for the length of integration, the frequency channel is discarded in subsequent integrations over time and frequency

The power in each frequency channel is summed and stored onboard both with and without RFI filtering. For testing purposes in this demonstration system, each frequency channel is also downlinked so that the effectiveness of the onboard RFI filtering algorithms can be evaluated in ground-based analyses.

4.3. RF Antennas

The radiometer antenna subsystem (Figure 4) is being designed and developed at The Ohio State University to provide a gain ranging from 12 dBi (at 6 GHz) to 21 dBi (at 40 GHz) in a circular polarization. A series of three tapered helical antennas are used to provide the necessary gain and efficiency, with distinct antennas used in differing portions of the 6-40 GHz bandwidth. The antenna is deployed from a stowed configuration once in orbit; the deployment mechanism is being developed in conjunction with BCT.

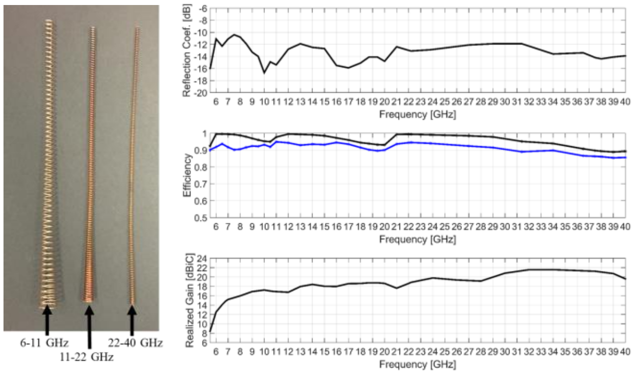

Figure 4. Tapered helical antennas used across the 6-40 GHz range of the radiometer

5. CONCEPT OF OPERATION

CubeRRT’s mission goals of evaluating on-board detection and filtering of RFI coupled with the limited solar cell and battery capacity of a 6U CubeSat bring about some unique challenges for payload operations. These challenges primarily reside with regard to scheduling power cycling and frequency tuning of the payload. In contrast to other radiometer missions, which typically aim to gather brightness temperature information of the entire Earth’s surface, CubeRRT’s power budget allows operation only at a duty cycle of approximately 30%. The system prioritizes operation over coordinates of known RFI sources and over landmasses where RFI is more likely to occur.

To assist in the modelling of these operations, a scheduler simulation tool was developed. This tool can be used to develop algorithms for power cycling and frequency tuning, which can then be propagated over the orbital lifetime to predict CubeRRT measurement information including the duration until mission-level requirements are fulfilled, radiometry coverage maps, as well as long-term battery depth-of-discharge (DOD) and payload data or telemetry profiles. In addition, the scheduler can be used to automate the process of generating payload command sequences for regular uplinking to the spacecraft.

To properly model the above, the scheduler simulates the power system, telemetry, RFI coordinates, and orbital propagation models. The power system state is modelled with knowledge of the available energy from CubeRRT’s solar cells, the known power draw from the satellite bus and payload subsystems, and the battery capacity. Telemetry and payload data buffers are monitored and downlinked at a known rate to the Wallops Flight Facility (WFF) to predict and prevent buffer overflow conditions. The current set of RFI locations were generated from existing radiometry datasets produced by previous nadir-observing radiometer missions (Jason and TRMM).

The general algorithm for power cycling involves three 10-minute blocks of payload operation within the orbit of approximately 90 minute duration, resulting in a 30% duty cycle, illustrated in Fig. 5. The payload orients the three blocks by first prioritizing observation of known RFI points, followed by land observation. If RFI and land are exhausted for a particular orbit, operation during maximum solar availability is then selected. If the chosen sequence exceeds a DOD threshold, the power sequence reverts to operating around peak sun. While the payload is operating, frequency tuning sequentially sweeps through the ten radiometer bands in 10-second increments.

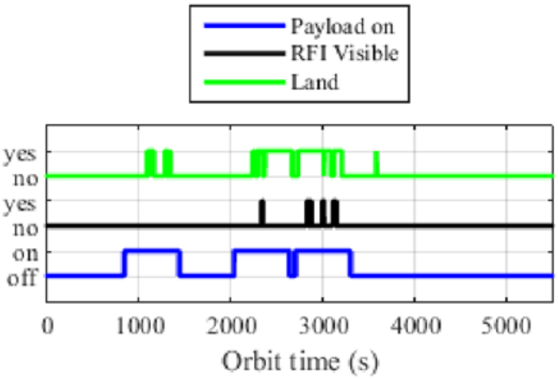

Figure 5. Illustration of simple orbit power cycling

This scheduling algorithm was propagated over the one year expected mission lifetime, with results shown in Fig. 6. The payload exhibits an RFI efficiency of approximately 98%, the percentage of time the payload operates when known RFI points are visible within the radiometer's footprint. The payload will spend approximately 65% of its operational time above landmasses. It will observe approximately 99% of available land within the latitude limits of an ISS deployed orbit at least once over the year of operation, excluding the South Atlantic Anomaly around eastern South America. The abundance of high energy particles in this region causes increased probability of single event upsets or latchups, and therefore payload operation in this region is avoided.

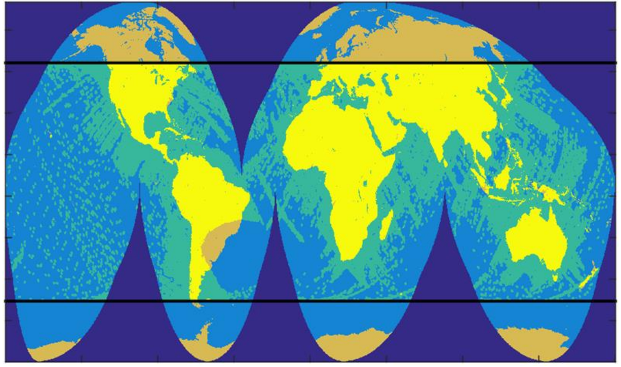

Figure 6. CubeRRT coverage at 6.8 GHz band over 1 year of operation

6. CONCLUSIONS AND NEXT STEPS

The CubeRRT system is being designed to meet an ambitious set of mission objectives in order to demonstrate and mature spaceborne RFI mitigation technology. The project will begin flight model development in 2017 with hardware delivery schedule for February 2018. Launch is anticipated in mid-2018 followed by 12 months of on-orbit operations.

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