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Qualification of the Radiometer Suite for the NASA TROPICS Tropical Cyclone Mission

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Abstract

The Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission was selected by NASA as part of the Earth Venture–Instrument (EVI-3) program and is now in development with planned launch readiness in late 2019. TROPICS comprises a constellation of six CubeSats in three low-Earth low-inclination orbital planes. Each CubeSat will host a high performance radiometer to provide temperature profiles using seven channels near the 118.75 GHz oxygen absorption line, water vapor profiles using three channels near the 183 GHz water vapor absorption line, imagery in a single channel near 90 GHz for precipitation measurements (when combined with higher resolution water vapor channels), and a single channel at 205 GHz that is more sensitive to precipitation-sized ice particles. Thermal vacuum test results on the qualification unit indicate that NEDTs will range from approximately 0.5 to 1.0 K for an 8.333 msec integration time. Spatial resolution at nadir ranges from approximately 15 km for the G-band channels to 30 km for the W-band channels.

1 Introduction

The Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission will provide rapid-refresh microwave measurements over the Tropics to observe the thermodynamics and precipitation structure of TCs over much of their lifecycle ([4]). TROPICS comprises six CubeSats (dual-spinning, 6.0-kg, 3 units or 3U) spread across three 550-km altitude, 30°-inclination orbital planes for a one-year science data collection period. Each CubeSat contains a 2U spacecraft bus and hosts a 1U high-performance 12-channel microwave radiometer scanning across the satellite track at 30 revolutions per minute (RPM) to provide both sounding (temperature and humidity, 2-3 km vertical resolution) and imaging capabilities. The sensor will include seven channels near the 118.75 GHz oxygen absorption line for temperature, three channels near the 183 GHz water vapor absorption line for moisture, a single channel at 90 GHz (combined with temperature and moisture channels) for precipitation structure detection, and a single channel near 205 GHz for larger cloud/smaller precipitation ice measurements. The full swath of the radiometer observations will be fully programmable and extendable to ±60° from nadir, with a 1.5° cross-track sampling interval (81 spots/swath) and fields-of-view (FOVs) comparable to the scale of warm thermal anomalies associated with TC cores.

The constellation members will be flown in a circular low-earth orbit in nearly equally-spaced orbital planes, with multiple satellites populating each orbital plane. The constellation will permit sampling of tropical cyclones with approximately 40-min median revisit rate. The spacecraft bus will be provided by Blue Canyon Technologies and will provide power & power conditioning, communications, on-board processing, thermal management, and attitude knowledge/control to the satellite. The flight software will provide command and control of the payload, and will interface with the bus communications system to manage payload commands and prepare payload telemetry for downlink.

2 Radiometer Characteristics

TROPICS will fly two total power radiometers that measure 12 channels spanning approximately 90 to 206 GHz. The "WF-band" radiometer comprises eight channels from 90–119 GHz, and the "G-band" radiometer comprises four channels from 183–206 GHz. The radiometer block diagram is shown in Fig. 1. The specific channel properties are shown in Table 1. The full-width at half maximum antenna beamwidths are achieved using an offset parabolic reflector illuminated with two electroformed feed horns that are physically separated, and the beams are combined and colocated using a polarizing wire grid diplexer. The antenna engineering model is shown in Fig. 2. Beam efficiencies for the temperature and water vapor sounding channels are designed to exceed 95%. Measureded F-band antenna patterns are shown in Fig. 3 and measured return loss of the G-band feedhorn is shown in Fig. 4. Excellent performance is indicated in both the pattern and return loss data. Radiometer calibration is accomplished using weakly coupled noise diodes with known and stable noise output that are turned on and off against the cold space background. Satellite intercalibration is optimized using cross comparisons ([1]) and daily calculated numerical model residuals ([2]) to derive and implement any needed bias correc-

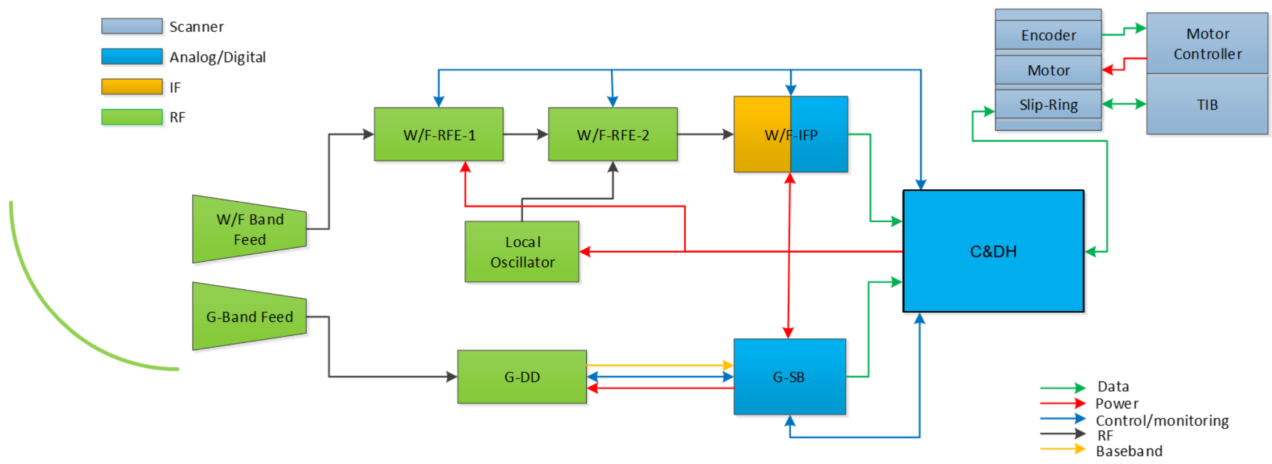

Figure 1. TROPICS radiometer block diagram.

Table 1. Description of the TROPICS Radiometer Channels

Chan.	Center Freq. (GHz)	Bandwidth (MHz)	Beamwidth (deg.) Down/Cross	Nadir Footprint (km)	NEDT	Cal. Acc. (K)
1	91.655 ± 1.4	1000	3.0/3.17	29.6	0.66	2.0
2	114.50	1000	2.4/2.62	24.1	0.96	1.5
3	115.95	800	2.4/2.62	24.1	0.82	1.5
4	116.65	600	2.4/2.62	24.1	0.86	1.5
5	117.25	600	2.4/2.62	24.1	0.79	1.5
6	117.80	500	2.4/2.62	24.1	0.81	1.5
7	118.24	380	2.4/2.62	24.1	0.90	1.5
8	118.58	300	2.4/2.62	24.1	1.03	1.5
9	184.41	2000	1.5/1.87	16.9	0.58	1.0
10	186.51	2000	1.5/1.87	16.9	0.55	1.0
11	190.31	2000	1.5/1.87	16.9	0.53	1.0
12	204.8	2000	1.35/1.76	15.2	0.52	1.0

tions. The W/F-band receiver assembly is shown in Fig. 5. A custom SiGe MMIC was developed at UMass-Amherst to provide and RF amplifier, mixer, and IF preamplifier in a highly integrated package.

The radiometer operates in an "integrate-while-scanning" mode that results in elongated footprints in the cross-track direction. The spatial resolution is thus reported as the geometric mean of the minor and major axes of the ellipse projected on the earth, also accounting for earth curvature. As the constellation of six satellites scans the earth, the footprints near the edge of the scan are revisited more often than the footprints near nadir. This is effect is quantified by calculating an "effective" spatial resolution that weights the spatial resolution of each footprint by the relative frequency by which it is revisited. The nadir, mean-across-scan, and effective spatial resolutions are shown in Table 2. The satellite pointing accuracy and sensor mounting requirements are set to ensure geolocation errors are smaller than approximately 10% of the footprint size.

Temperature weighting functions for all 12 TROPICS chan-

Table 2. TROPICS spatial sesolution (shown in km) for W, F, and G-band channels are shown at nadir and averaged over the 81 footprints in the swath. Also shown is the "effective" spatial resolution that accounts for how often the footprints are revisited across the scan (see text for details).

Band	Nadir	Scan Mean	Effective Across Scan
W (90 GHz)	29.6	42.9	50.7
F (118 GHz)	24.1	34.9	41.2
G (183 GHz)	16.1	23.3	27.5
G (205 GHz)	15.2	22.1	26.0

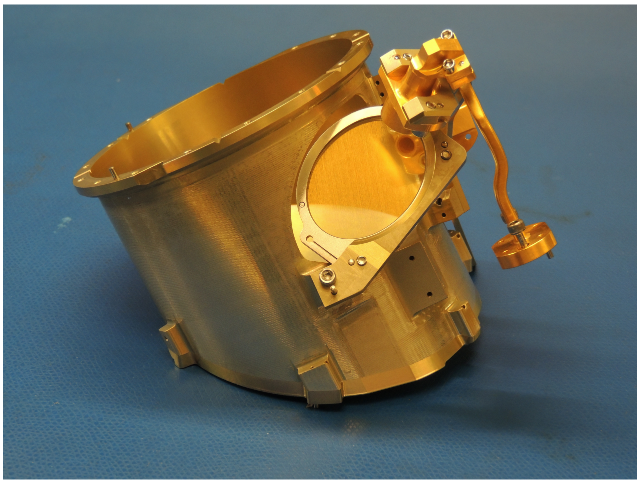

Figure 2. TROPICS antenna assembly qualification unit. The 90-120 GHz feedhorn is visible in the front of the photo, and the 180-205 GHz feedhorn can be seen through the wire grid.

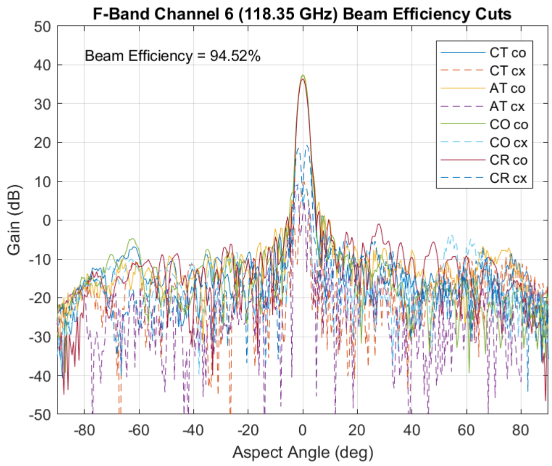

Figure 3. Measureded antenna patterns at F-band for the complete TROPICS antenna assembly qualification unit, including shroud and waveguide.

nels are shown in Fig. 6. Channel passbands are designed to span altitudes from the surface up to 20 km for temperature and 10-km for water vapor. Multiple temperature channels probe the upper troposphere to observe tropical cyclone warm core anomalies.

Figure 4. Measured return loss at G-band for feedhorn, including waveguide (figure courtesy Thomas Keating, LTD).

References

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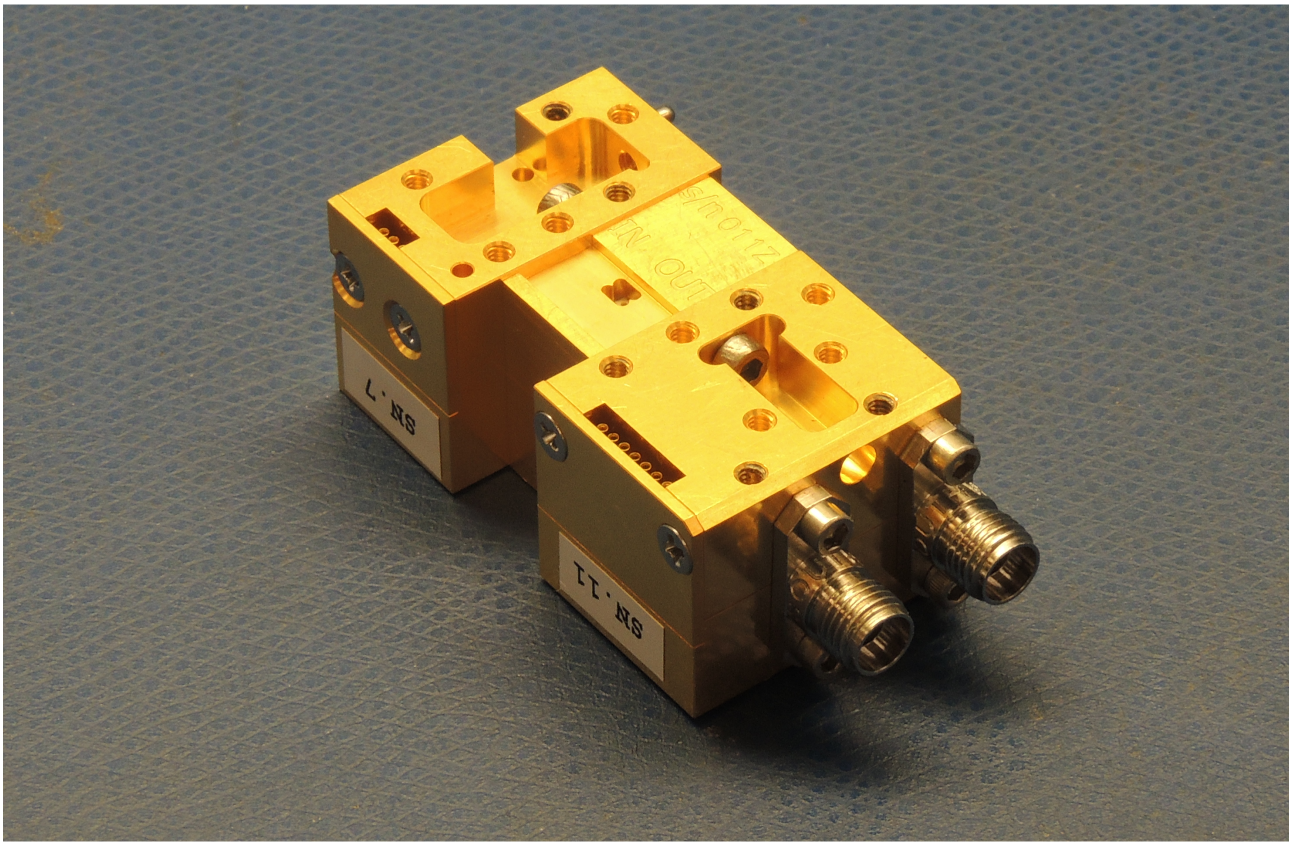

Figure 5. The TROPICS W/F-band receiver assembly developed by UMass-Amherst, comprising the coupled noise diode module, the RF preamplifier module, and the SiGe mixer/tripler/amplifier module.

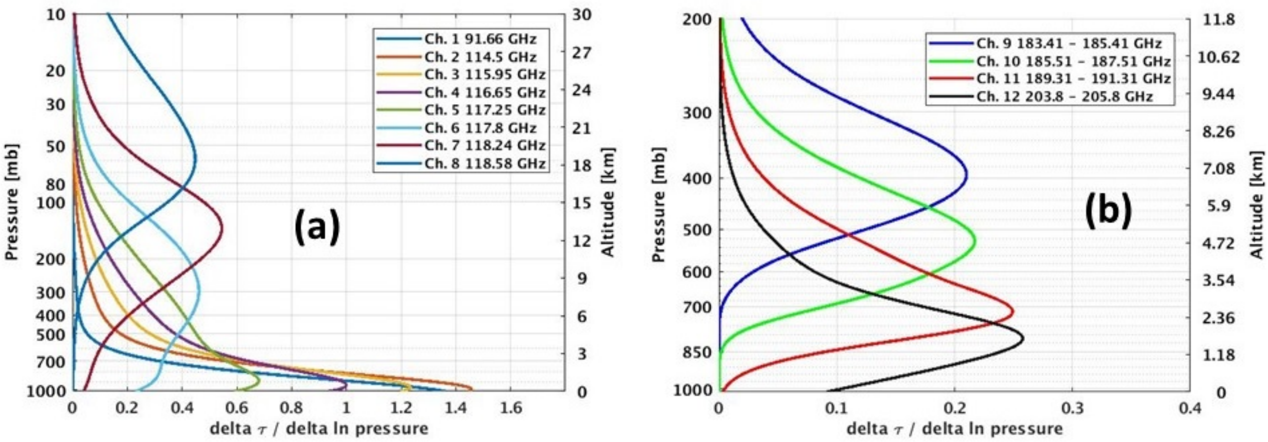

Figure 6. Weighting functions calculated at nadir incidence over a perfectly emissive surface for a standard tropical atmosphere for both a) temperature/imaging and b) water vapor/imaging channels.