Tropospheric Water Vapor and Cloud ICE (TWICE) Millimeter- and Submillimeter-wave Radiometer Instrument for 6U-Class Nanosatellites

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Tropospheric Water Vapor and Cloud Ice (TWICE) Radiometer

Measurements of upper-tropospheric water vapor and cloud ice at a variety of local times are critically needed to address current limitations of microwave sensors in sun-synchronous orbits. Such global measurements would improve currently limited understanding of upper tropospheric / lower-stratospheric (UTLS) processes in general circulation models (GCMs), improving both climate predictions and knowledge of their uncertainty.

Clouds and Aerosols

- Clouds represent the largest uncertainty in predictions of climate models. Clouds in polluted environments tend to have smaller water droplets and ice crystals than those in cleaner environments. As shown in Figure 1, they are less likely to generate rainfall, increasing the cloud water content, and have higher albedo than clean clouds.

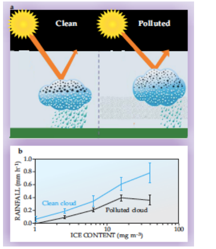


Figure 1. Ice water content data from Aura MLS, with TRMM rainfall observations, demonstrate that for a given ice content, clouds in polluted environments produce less intense rainfall. From L'Ecuyer and Jiang, *Physics Today*, 2010; Jiang et al., *GRL*, 2008.

Ice Cloud Particle Size

- NASA's A-Train provides limited cloud particle size information. Sub-millimeter wave radiometry can fill the gap between large particle sizes from CloudSat's 94-GHz radar and small particle sizes from Aqua MODIS 10-µm infrared radiometer.
- Sub-millimeter wave radiometry can provide cloud particle size information between approximately 25 µm and 1 mm.
- High atmospheric opacity at sub-millimeter wavelengths allows the measurement of high cirrus clouds through scattering.
- Brightness temperatures decrease below the ambient water vapor continuum by different amounts at different frequencies, depending on ice particle size, as shown in Figure 2.

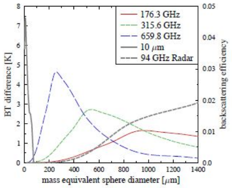


Figure 2. Sensitivity of millimeter- and sub-millimeter wave measurements at different frequencies to particle size. Adapted from Buehler et al., *QJRMS*, 2007.

TWICE Instrument Top-Level Design

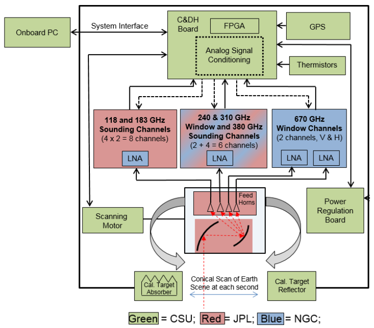


Figure 3. TWICE Block Diagram

TWICE is managed by the NASA Earth Science Technology Office under the Instrument Incubator Program. TWICE is a collaborative effort led by Colorado State University (CSU) in partnership with the NASA Jet Propulsion Laboratory (JPL) and Northrop Grumman Corporation (NGC).

TWICE is intended to provide global measurements of ice particle size through based on radiometric measurements performed at 240 GHz, 310 GHz, 670 GHz, and 850 GHz as well as provide temperature and humidity profiles using 118 GHz (temperature), 183 GHz (water vapor), and 380 GHz (upper tropospheric water vapor) sounding channels.

TWICE instrument is designed for deployment in a 6U-Class satellite and has a mass of 7.3 kg.

TWICE Design and Quasi-Optics

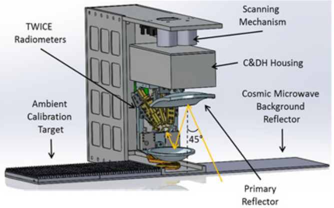


Figure 4. TWICE CAD Model

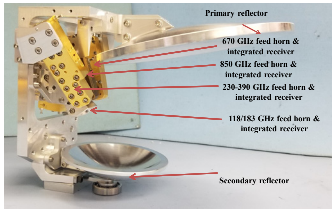


Figure 5. TWICE Quasi-Optics

TWICE radiometers will perform conical scanning to preserve the polarization basis.
The TWICE instrument performs end-to-end, two-point, on-orbit radiometric calibration by observing an ambient temperature calibration target (≈300 K) and cold sky reflector (≈2.7 K) during each scan cycle.

The TWICE quasi-optics utilize a scaled version of the Planck telescope design that is scaled by a factor of 15 to about 10 cm aperture.
To minimize aberrations, 670 GHz and 850 GHz feed horns are closest to the optimum center of the quasi-optical focal plane.

TWICE Ambient Calibration Target

The TWICE ambient calibration target is designed to provide a return loss of at least 15 dB at all 16 TWICE frequencies.
Due to its high thermal conductivity and more than 20 dB return loss at TWICE frequencies, the C-RAM RGD material was chosen for the TWICE ambient calibration target.

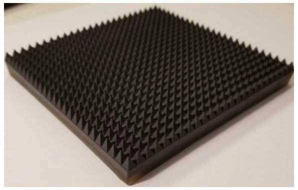


Figure 6. TWICE Ambient Calibration Target

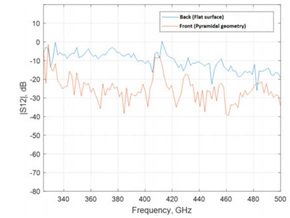


Figure 7. Measured return loss of TWICE Ambient Calibration Target

TWICE Scanning Strategy

For a CubeSat deployment from the International Space Station into an orbit with 400 km altitude and 51.6° inclination:

- TWICE conically scans the scene with a nominal incidence angle of 53°, viewing the Earth scene swath over a scan angle range of 110°.
- TWICE has a swath width of 650 km and a scan-to-scan along-track displacement of 7.2 km, assuming a scan duration of 1 s. The relative sizes and locations of the geo-projected footprints are shown in Figure 8.

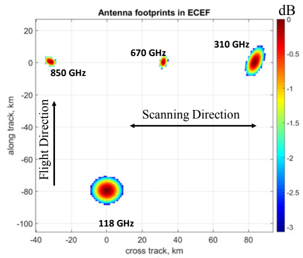


Figure 8. Geo-projected sizes and locations for 400 km LEO orbit and -3 dB beam patterns at the 118, 310, 670 and 850 GHz TWICE frequencies.

118 and 183 GHz Receiver Modules

The TWICE 118 and 183 GHz integrated receiver modules use technology previously developed for ESTO-sponsored GeoSTAR IIPs, SWOT ACT-08 and HAMMR IIP-10.

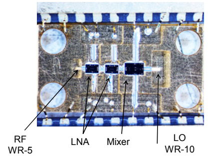


Figure 9. 183 GHz Receiver Module

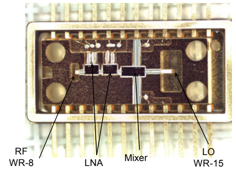


Figure 10. 118 GHz Receiver Module

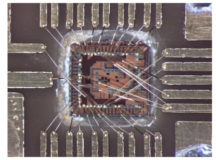


Figure 11. ASIC IF Processor

230 GHz, 310 GHz and 380 GHz Integrated Receiver

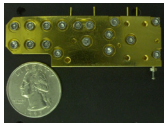
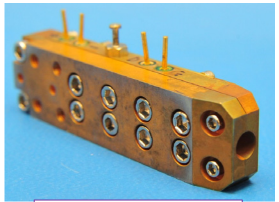


Figure 12. 230-380 GHz Receiver Housing

The 230 and 310 GHz receivers are direct-detection receivers with noise figures (NF) of 9.7 dB and 8.5 dB, respectively. The 380 GHz sounder is a heterodyne four-channel receiver with NF of 7.5-9 dB across the bandwidth. The integrated receiver housing also includes a highly compact single feed horn as well as integrated diplexers and bandpass filters.

670 GHz and 850 GHz Integrated Receivers



Dimensions: 4.8 x 1.3 x 0.8 cm

Figure 14. 670 GHz Integrated Receiver (850 GHz receiver has the same design.)

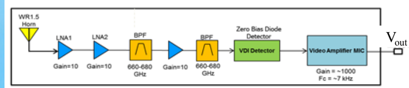


Figure 13. Block Diagram of 670 and 850 GHz Integrated Receivers

Receiver	Power Consumption	Noise Figure	Frequency Band
670 GHz	270 mW	11.2 dB	650-680 GHz
850 GHz	200 mW	15.4 dB	770-860 GHz

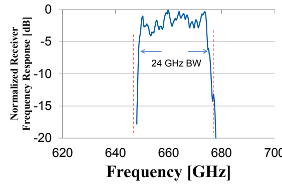


Figure 15. Frequency Response of 670 GHz Receiver

CONCLUSIONS

- The Tropospheric Water and Cloud ICE (TWICE) is a 6U-Class satellite instrument to enable global measurements of cloud ice particle size distribution and water vapor profiles in the upper-tropospheric/lower stratosphere (ULTS) at a variety of local times.
- TWICE performs measurements at 16 frequencies from 118 GHz to 850 GHz to yield cloud ice particle size information and total ice water content as well as atmospheric profiling of temperature and water vapor.
- Conical scanning preserves the polarization basis and enables end-to-end calibration at all 16 frequencies using cosmic microwave background and an ambient blackbody calibration target.
- The TWICE instrument meets the size, weight and power (SWaP) requirements for deployment in a 6U-Class satellite.