Development of MMIC-based High-Frequency Microwave Radiometers to Improve Wet-Tropospheric Delay Correction in the Coastal Zone

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Introduction

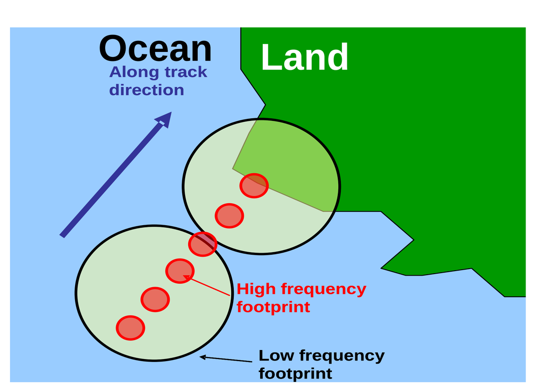
Conventional satellite ocean altimeters, including Jason-2/OSTM and the upcoming Jason-3, include nadir-viewing, co-located 18-34 GHz (TOPEX up to 37 GHz) multi-channel microwave radiometers to measure wet-tropospheric path delay. Due to the area of the surface instantaneous fields of view (IFOV) at these frequencies, the accuracy of wet path retrievals begins to degrade at approximately 40 km from the coasts. In addition, conventional microwave radiometers do not provide wet-path delay over land. The addition of higher-frequency millimeter-wave (90-170 GHz) radiometers to current Jason-class radiometers is expected to improve retrievals of wet-tropospheric delay in coastal areas and to increase the potential for over-land retrievals.

Scientific Motivation

Higher-frequency radiometers with internal calibration are under development to assess their ability to meet the needs of the Surface Water and Ocean Topography (SWOT) mission recommended by the U.S. National Research Council's Earth Science Decadal Survey, accelerated in 2010 and planned for launch in 2020. The primary objectives of SWOT are to characterize ocean sub-mesoscale processes on 10-km and larger scales in the global oceans, and to measure the global water storage in inland surface water bodies. The SWOT radar interferometer will for the first time broaden the field of view and improve spatial resolution to make coastal and inland surface water measurements, so the variability of atmospheric water vapor across the swath will affect the accuracy of sea surface altimetry. In this context, addition of higher-frequency, millimeter-wave (90-170 GHz) channels to the Jason-class radiometers will improve retrievals in coastal regions and show good potential to provide retrievals over land.

SWOT Mission Concept Study at JPL

A radiometer simulator and a coupled, high-resolution Weather Research and Forecasting model were used to assess retrieval performance and determine instrument requirements.



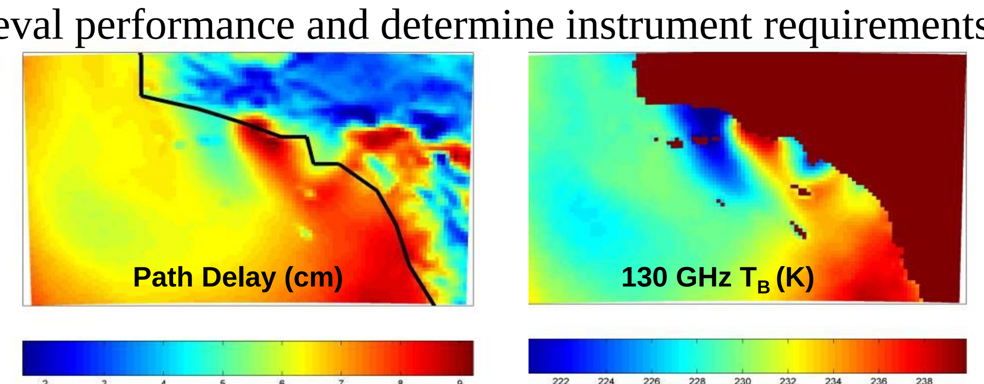


Fig. 1. Radiometer simulator results off Southern California

Fig. 2. Improved spatial resolution using advanced, high-frequency radiometers from 90-170 GHz as compared to using conventional radiometers at 18-34 GHz

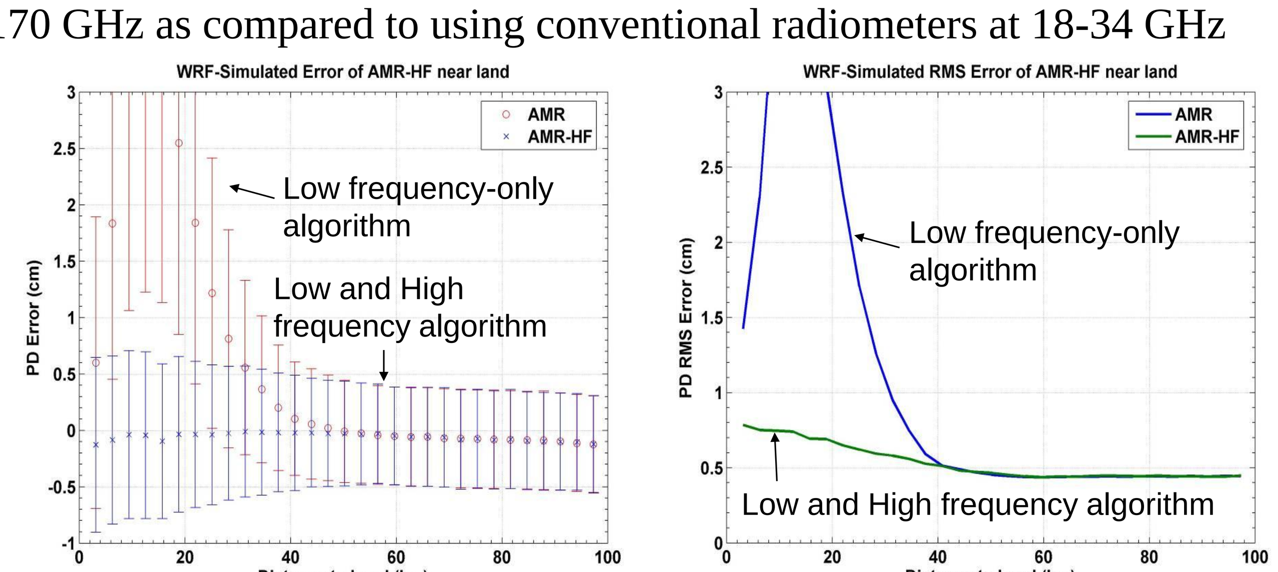


Fig. 3. High-resolution WRF model results show reduced wet path-delay error using both low-frequency (18-34 GHz) and high-frequency (90-170 GHz) radiometer channels.

Simulation results show that addition of wide-band millimeter-wave window channels at 92, 130 and 166 GHz to the Jason-class radiometers will improve retrievals in coastal regions and show good potential to provide retrievals over land.

Advanced Component Development

Development of internally-calibrated millimeter-wave radiometers at these three center frequencies requires demonstration of new component technology, i.e. (1) low-power, low-mass and small-volume direct-detection millimeter-wave radiometers with integrated calibration sources, and (2) a multi-frequency feed horn covering the same frequency range. We have demonstrated three key component technologies to achieve these objectives, i.e. a PIN-diode switch for internal calibration that can be integrated into the receiver front end, a high-Excess Noise Ratio (ENR) noise source and a single, tri-frequency feed horn. These new components have been integrated into a monolithic microwave/millimeter-wave integrated circuit (MMIC)-based radiometer with channels centered at 92, 130 and 166 GHz.

Radiometer System Design

New millimeter-wave components have been fabricated, tested and integrated into a MMIC-based low-mass, low-power, small-volume radiometer at 92, 130 and 166 GHz. This radiometer will serve as a breadboard demonstration by providing realistic mass, volume and power estimates to feed into the mission concept study.

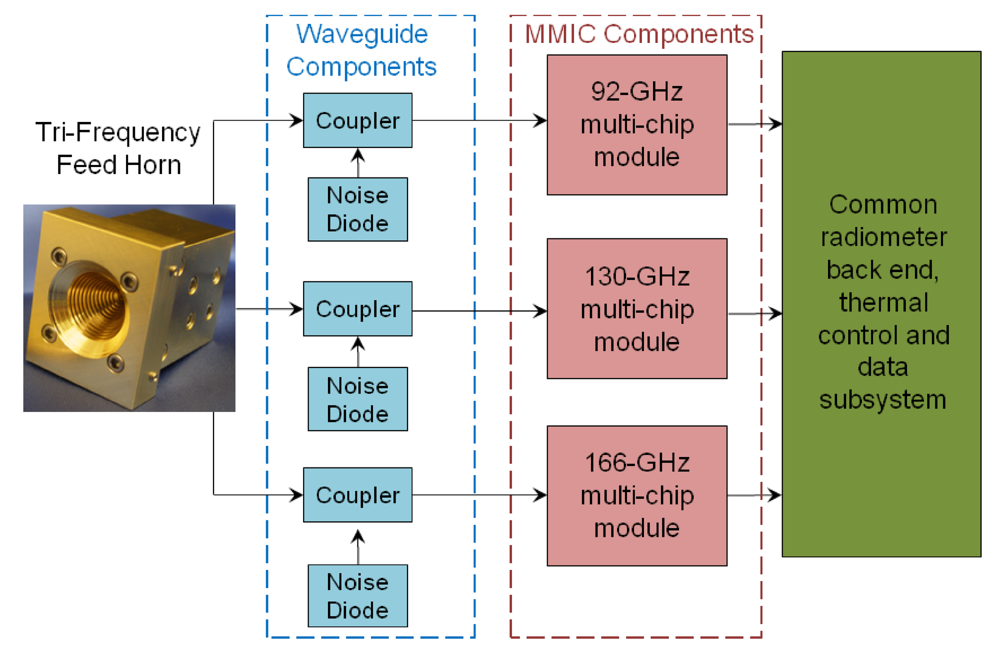


Fig. 4. MMIC-based high-frequency radiometer block diagram

Development of Passive Millimeter-Wave Components

Passive millimeter-wave, MMIC-compatible components for this radiometer have been custom designed at Colorado State University, including millimeter-wave band-definition filters, attenuators and probes to couple energy from the waveguide antenna input to microstrip transmission lines.

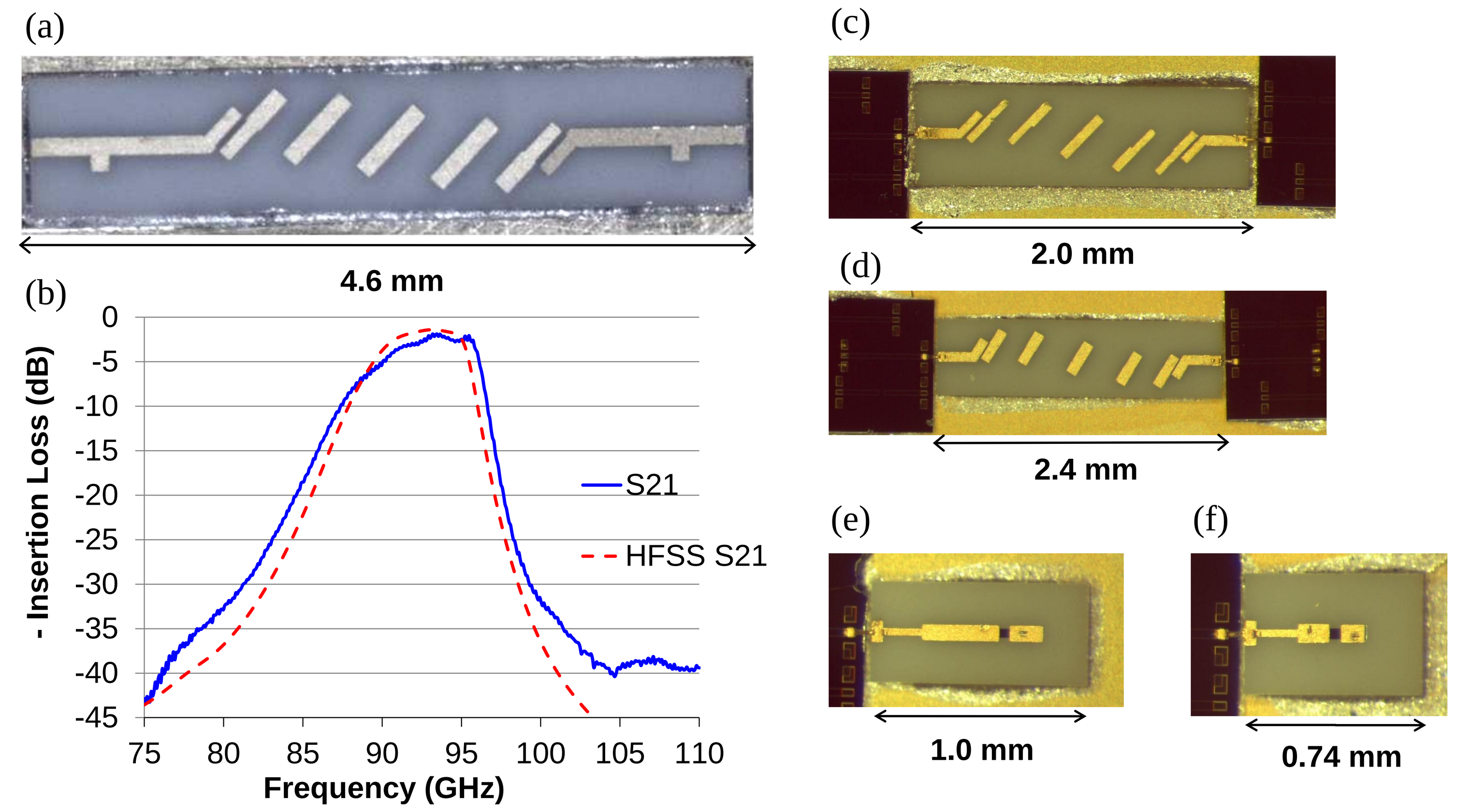


Fig. 5. (a) Millimeter-wave bandpass filter centered at 92 GHz, (b) measured and simulated insertion loss in air; (c) and (d) are filters at 130 and 166 GHz, respectively; (e) and (f) are matched-load terminations for 130 and 166 GHz, respectively. All components show good agreement between measured results and simulations.

Integrated Calibration Switches

Integrated calibration noise sources and front-end switches are required by the fixed viewing geometry of the radiometer, making cold sky or blackbody calibration infeasible. MMIC-based PIN-diode switches have been designed by JPL and fabricated by Northrup Grumman Space Technology (NSGT) for the 90-180 GHz frequency range.

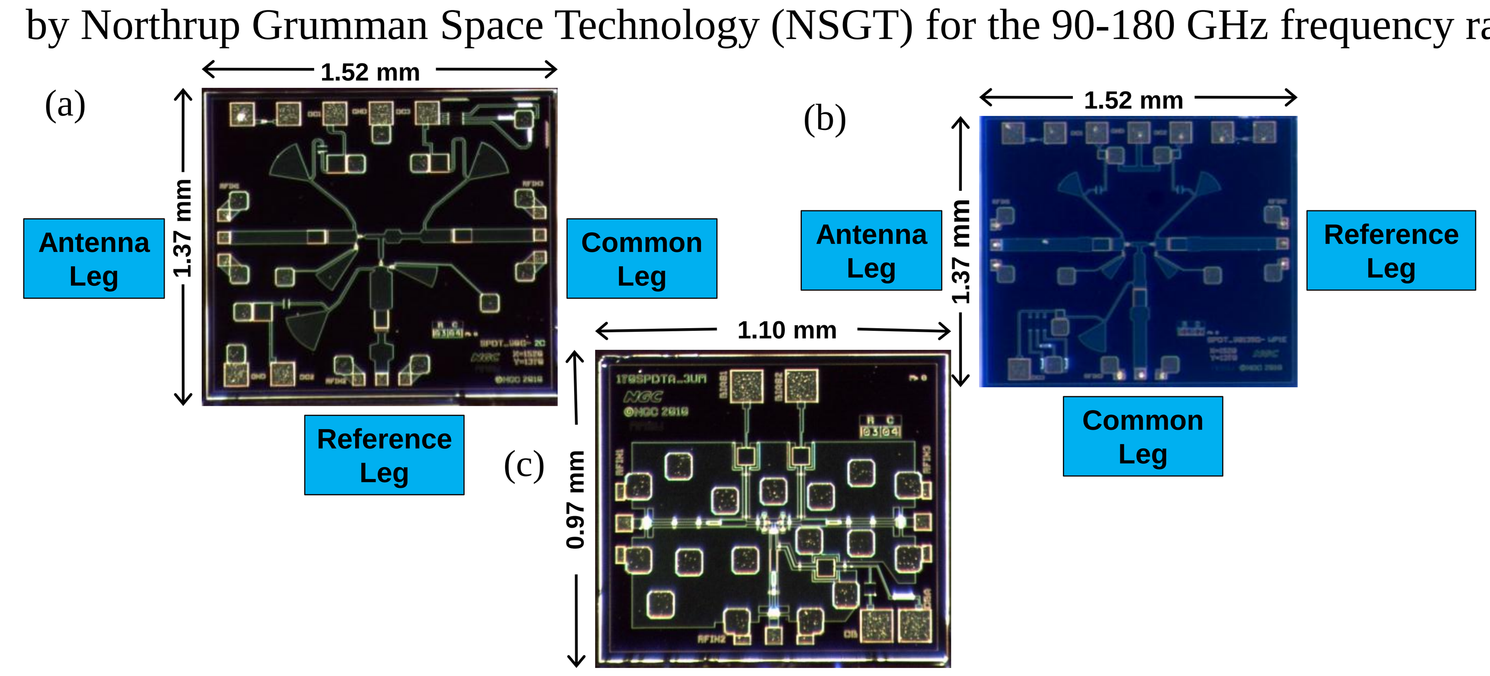


Fig. 6. PIN-diode switches designed, fabricated and tested for (a) 80-105 GHz, (b) 90-135 GHz and (c) 160-185 GHz. Measurements show that these switches meet requirements.

MMIC Multi-Chip Modules for SWOT-ACT Radiometer

An LNA-based front end is required to achieve the low noise figure for this technique, and direct detection is the lowest power and mass solution for these high-frequency millimeter-wave radiometers. Keeping the radiometer power at a minimum is critical to fit within the overall SWOT mission constraints. Commercially-available MMIC active components are implemented in the multi-chip module at 92 GHz, and record low-noise temperature LNAs developed by JPL and NGST are used at 130 and 166 GHz.

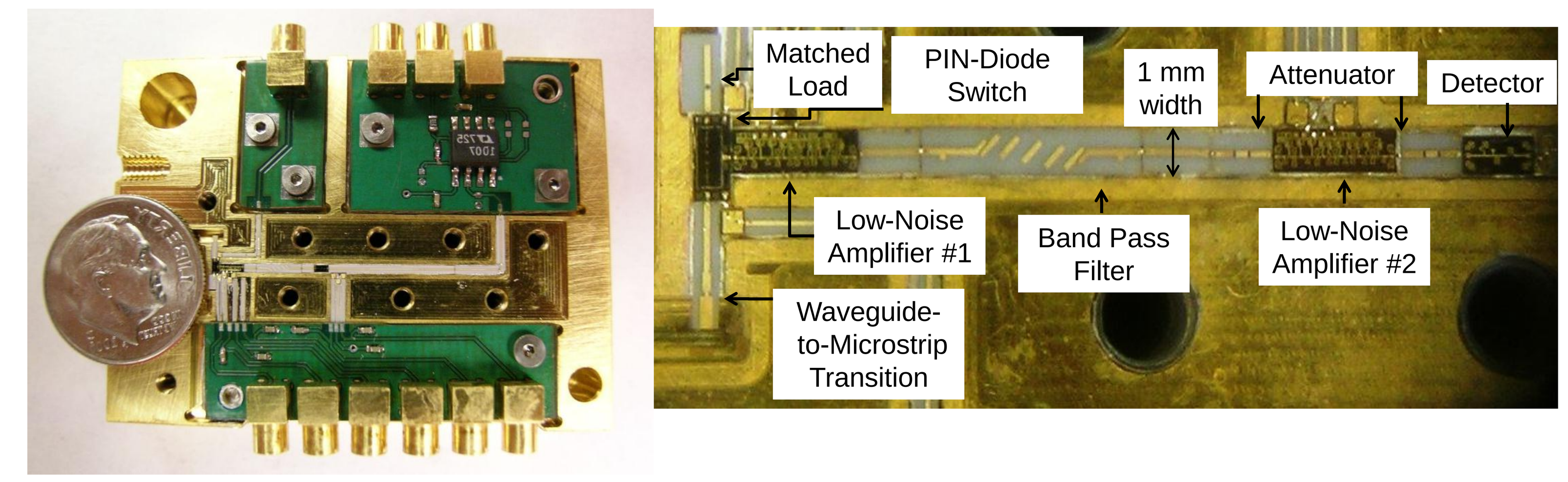


Fig. 7. Multi-chip module for 92-GHz radiometer, bottom half in full view (left) and detailed view (right).

Tri-Frequency Feed Horn for SWOT-ACT Radiometer

A single, multi-frequency feed horn and triplexer is required to maintain acceptable antenna performance, since separate feeds for the each of the high-frequency channels would need to be moved further off the antenna focus, degrading this critical performance factor. The tri-frequency horn was custom designed and produced at JPL, with an electroform combiner from Custom Microwave, Inc. Measurements show very good agreement with simulated results.

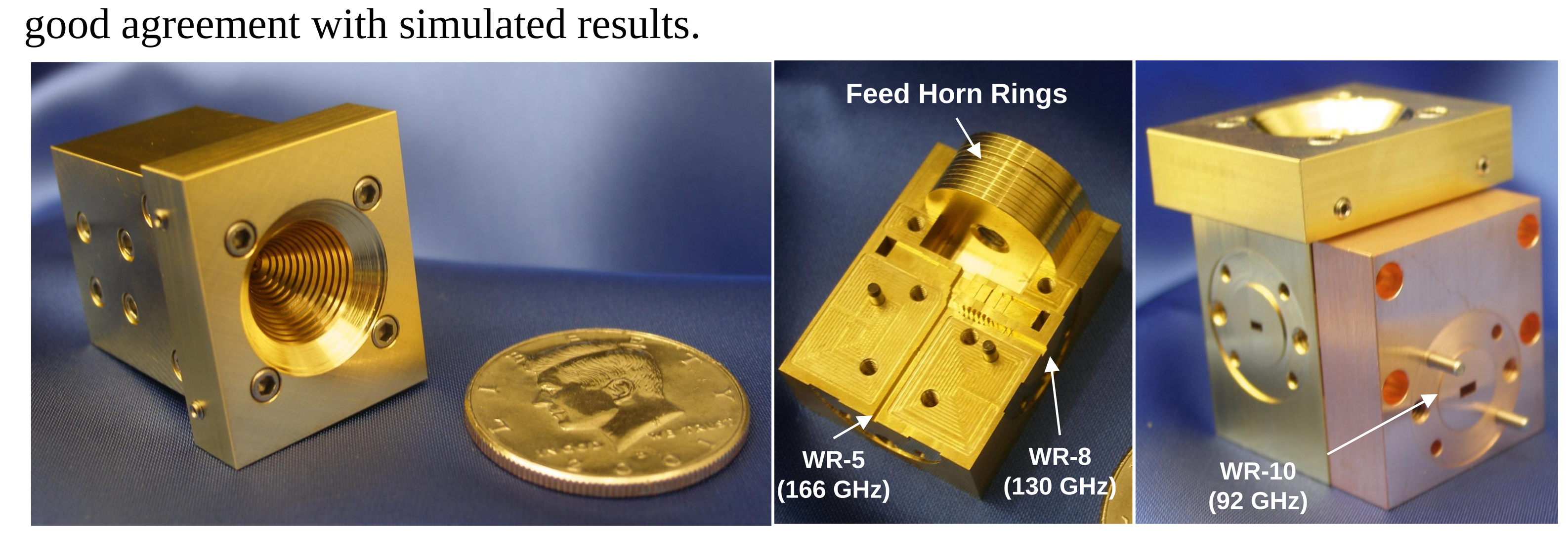


Fig. 8. Integrated, multi-frequency feed horn and triplexer with three waveguide outputs.

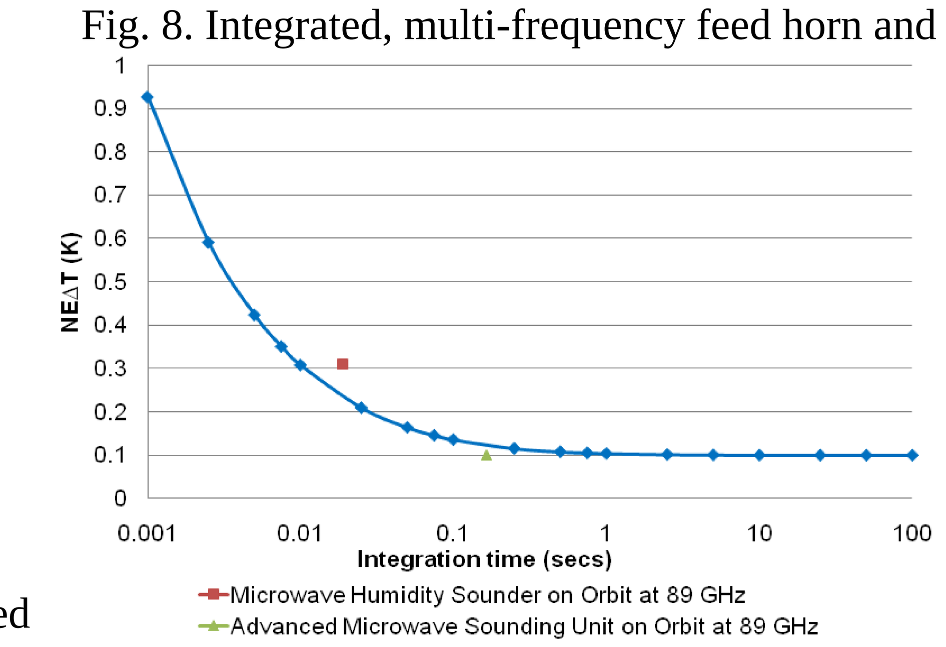


Fig. 9. Radiometric resolution at 92 GHz based on measured noise temperature.

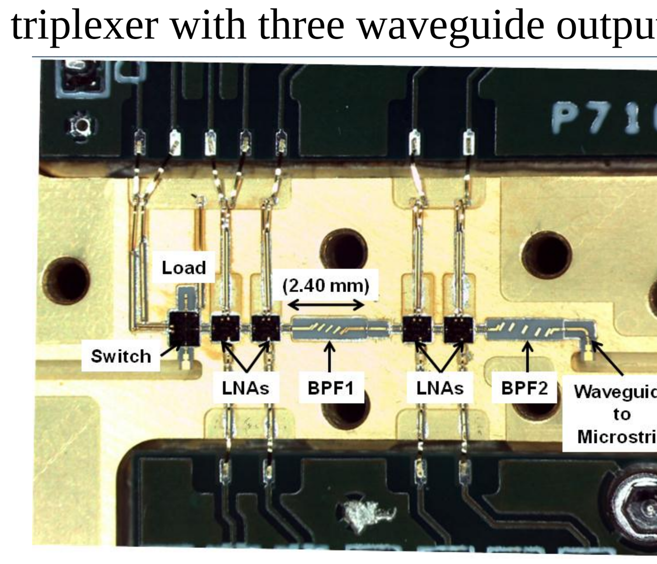


Fig. 10. Detailed view of integrated multi-chip module at 166 GHz.

Summary and Next Steps

The laboratory demonstration radiometer will be completed in early 2012. To reduce the risks associated with wet-tropospheric path delay correction over coastal areas and land, we will develop, build and flight test an airborne radiometer including high-sensitivity millimeter-wave (90-170 GHz) radiometers with substantially improved spatial resolution and the potential for multiple fields of view across the radar's swath. This instrument development and airborne flight demonstration will (1) assess wet-tropospheric path delay variability on 10-km and smaller spatial scales, (2) demonstrate millimeter-wave radiometry using both window and sounding channels to improve both coastal and over-land retrievals of wet-tropospheric path delay, and (3) provide an instrument for calibration and validation in support of the SWOT mission.