Radiometer Testbed Development for SWOT

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***Abstract* — Conventional altimeters include nadir looking co-located 18-37 GHz microwave radiometer to measure wet tropospheric path delay. These have reduced accuracy in coastal zone (within ~50 km from land) and do not provide wet path delay over land. The addition of high frequency channels to Jason-class radiometer will improve retrievals in coastal regions and enable retrievals over land. High-frequency window channels, 90, 130 and 166 GHz are optimum for improving performance in coastal region and channels on 183 GHz water vapor line are ideal for over-land retrievals.**

We have developed MMIC LNAs that had more than 50% lower noise temperature (NT=300K) than previous state-of-art. The MMIC LNAs enabled us to develop internally calibrated direct detect radiometer testbeds at the required observation frequencies. Our current 166 GHz radiometer testbed system has a noise temperature of 455 K, bandwidth of 10% and operates with 60 mW of DC power.

***Index Terms* — microwave radiometry, humidity measurement, monolithic millimeter wave integrated low noise amplifier, internally calibrated radiometer.**

I. Introduction

Ocean altimetry missions have provided valuable scientific information and prompted NRC to recommend in Earth Science decadal study a new mission, Surface Water Ocean Topography (SWOT). The primary objective of SWOT is to measure for the first time mesoscale phenomena (few-hundred km scale) in the global oceans, as well as the surface height of terrestrial water bodies (such as rivers, lakes, reservoirs, and wetlands) to advance inland hydrology. An important new science objective of SWOT is to transition radar altimetry into the coastal zone, necessitating a novel radiometer to provide high-spatial resolution wet-tropospheric path delay corrections near land. The addition of high-frequency microwave window channels (above 90 GHz) to the baseline low-frequency (around 22 GHz) water vapor correction channels is a viable approach to provide the required wet-tropospheric path delay correction to the radar altimeter measurements in coastal regions. This improvement relies on the inherently finer spatial resolution of microwave radiometer channels at higher frequencies, for a maximum antenna aperture size. High-frequency microwave channels in the atmospheric transmission windows, which are sensitive to the water vapor continuum, can be used to improve the retrieval of wet-tropospheric path delay in coastal regions by enabling extrapolation of the low-frequency measurements to the coast.

Over the open ocean, where spatial resolution is not as critical, only the low-frequency brightness temperatures (TBs) would be used, and the path-delay retrieval performance would be equivalent to that of current space-based altimeters, better than 1 cm RMS. As the radiometer approaches land, the low-frequency TBs will be contaminated by the coastline, and the high-frequency TBs will be used to extrapolate the path delay from the last uncontaminated ocean pixel to the coast. A simple statistical algorithm was investigated as a part of the concept study to estimate the path delay using the high-frequency TBs. The concept study has indicated that the addition of three high-frequency radiometer channels centered at 92, 130 and 166 GHz could yield path delay retrievals with an RMS error of less than 1 cm to within 3 km from the coast, which is in the acceptable range of errors for SWOT.

The current JPL built and commercial water vapor radiometers have mixer front ends and achieve NT=1500 to 2500 K (NF=7.0 to 9.8 dB) in double sideband (DSB) measurements [1],[2]. Recent mixer results show NT=500 to 600 K (NF=4.4 to 4.9 dB) DSB [3], which would indicate that they would perform better than most previously reported MMIC low noise amplifier (LNA) modules [4], [5]. We reported LNA module results NT=300 to 350K (NF=3.1 to 3.3 dB) in this band[6],[7] and complete direct detection radiometer with noise temperature of 455 K.

II. LNA Modules

The receiver development was based on a high performance 35 nm gate length InP HEMT MMIC LNAs [6]. The MMICs were developed in previous programs and optimized split block LNA modules were designed in the current project. The noise temperature of the receiver is dictated by the first LNA MMIC. The set-up for the noise figure measurement is shown in Fig. 1 [6]. The LNA had an input horn (WR-05 waveguide) and was followed by a double sideband mixer. We used an absorber as our hot and cold noise source in the Y-factor measurements. The hot temperature was the ambient (T= 295 K) and for cold load we dipped the absorber in liquid nitrogen (T=78 K) [6]. Fig. 2. shows noise temperature of 300 K at 150 to 160 GHz for this LNA module [7]. The MMIC LNA was also packaged in a WR-08 housing and measured in a similar setup as the WR-05 LNA. These results are also presented in Fig. 2 to demonstrate the broadband capability of the MMIC design. These results include the horn antenna, the waveguide inside the housing and waveguide to microstrip transitions.

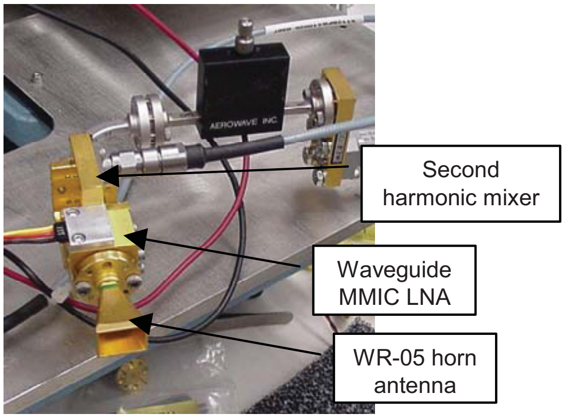


Fig. 1. Testing of the noise figure of the MMIC LNA in split block waveguide package (WR-05) [6].

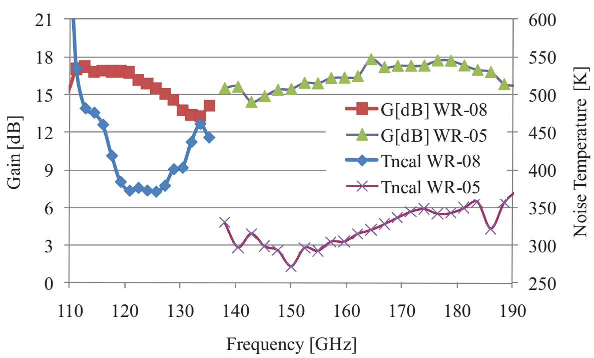


Fig. 2. Measured results for the waveguide MMIC LNA in optimized WR-05 and WR-08 waveguide housings. The noise temperature (Tncal) of the MMIC LNA is 300 K at 150 to 160 GHz frequency range [7].

III. DIRECT DETECT RADIOMETERS

These LNA modules enabled us to design direct detection radiometer test beds. These do not require local oscillators and operate with very low DC power. The radiometers are a cascade of two or three LNA modules, band definition filter and detector. The properties of the direct detection radiometers are summarized in table 1.

Table 1. Characteristics of the radiometer test beds

	92 GHz	130 GHz	166 GHz
Gain	40dB	40dB	45dB
Receiver NT	340 K	340 K	455 K
Bandwidth	10%	10%	10%
DC Power	40mW	40mW	60mW

Fig. 3. shows a picture of our current test bed radiometer system that has a noise temperature of 455 K, bandwidth of 10% and operates with 60 mW of DC power [7]. The testbed systems for the other frequency channels are similar cascades of individual components. This enables us to test different components for the radiometer and calibration system at all frequency channels.

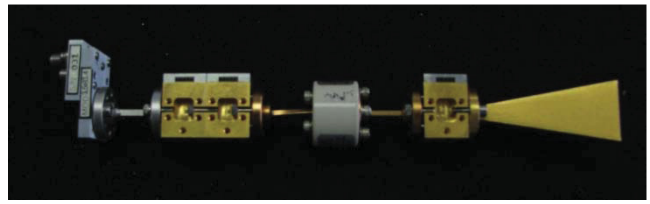
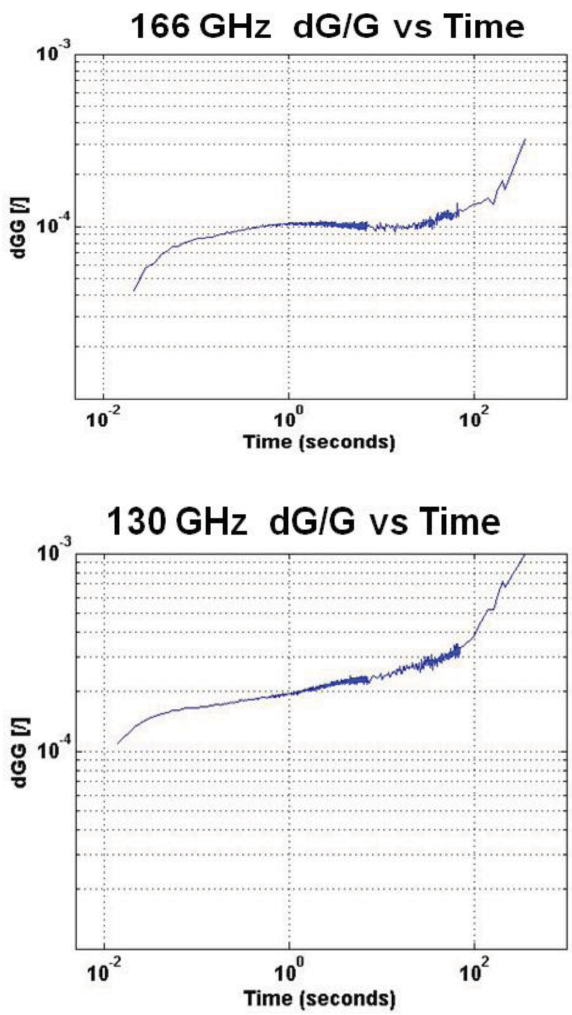


Fig. 3. Direct detection 166 GHz total power radiometer for the SWOT testbed [7].

After the initial functional tests of the radiometer testbed channels we performed gain stability tests. These are shown in Fig 4. for all channels. The gain stability of the radiometer testbeds was better than 2e-4 for up to 30 s.



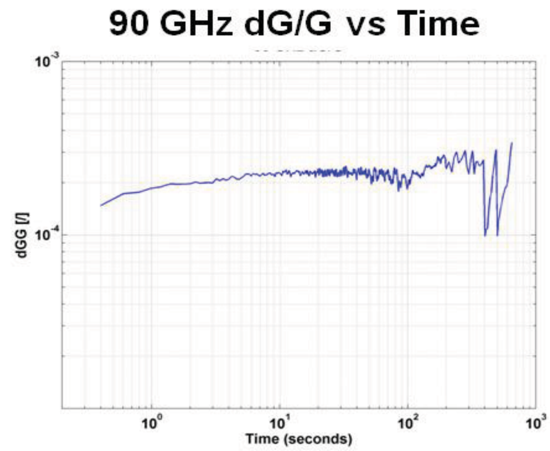


Fig. 4. Radiometer testbeds exhibit DG/G ~ 2e-4 or better to 30s

The radiometer testbed tests were continued with temperature stability tests. The 166 GHz radiometer had a gain temperature coefficient of 1.3%/C (0.06dB/C) and receiver noise temperature change of 2K/C as is shown in Figure 5.

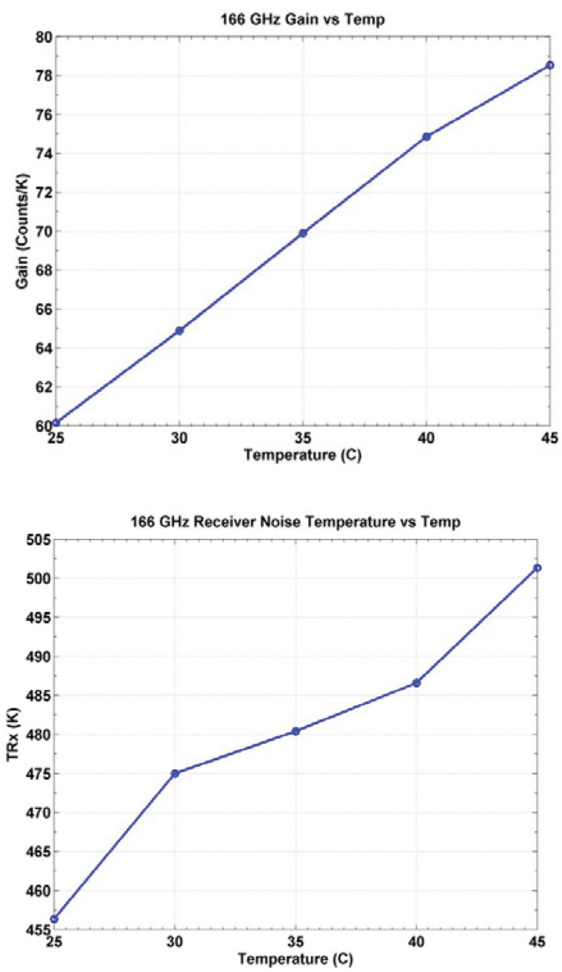


Fig. 5. 166 GHz radiometer test bed gain and noise temperature vs temperature

The test setup for these tests is shown in Fig. 6.

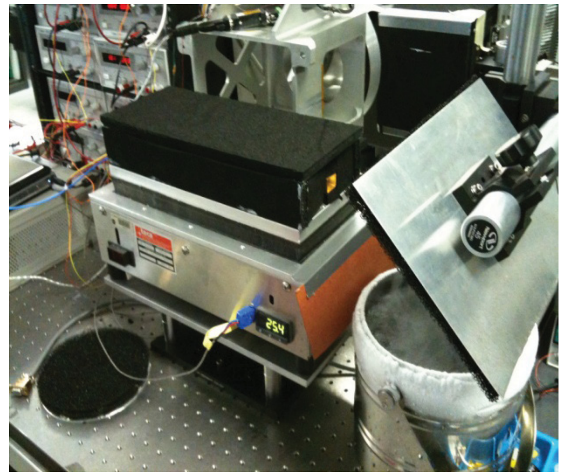


Fig. 6. Test set-up for temperature stability measurements

IV. Internal Calibration

Measurement noise depends on scene NEΔT and noise from calibration. Assuming 2 C/orbit total thermal variation, 2 dB front end loss, 0.1 s integration time and 1 second calibration averaging window the requirements for 2-point calibration TB difference (e.g. ENR of noise source) can be determined. The achievable NEΔTs with different equivalent noise temperatures and for each frequency channel are listed in table 2.

Table 2. Radiometer testbed TB difference (ENR) requirements for given NEΔT.

Cal TB difference	90 GHz	130 GHz	166 GHz
20	0.13	0.13	0.16
50	0.11	0.11	0.093
150	0.10	0.10	0.083
300	0.10	0.10	0.082

We are in the process of adding the internal calibration noise sources and SPDT Dicke switches to the radiometer channels. The noise source development is carried out in SWOT ACT project that is lead by Steve Reising from CSU. These individually packaged noise sources will be added to the testbed and tested for stability [8]. An InP PIN diode SPDT MMIC run was recently completed [8] and after the on-wafer tests of the MMICs we will package the switches to split block waveguide housings for testing in the testbeds.

V. Conclusion

The developed MMIC LNAs had the lowest reported noise figure at 160 GHz frequency band of receivers operating at ambient temperature. The developed 166 GHz radiometer testbed has small size, very low power consumption and mass, because of the direct detection mode of operation. These developed MMIC radiometer testbeds will demonstrate and test critical technologies for the SWOT radiometer development. The waveguide MMIC LNAs and radiometer testbeds were developed in ESTO IIP-07 task "Ka-band SAR Interferometry Studies for the SWOT Mission". The MMICs for this task were available from "Miniature MMIC Low Mass/Power Radiometer Modules for the 180 GHz GeoSTAR Array (MIMRAM)" technology development task within the ESTO Advanced Component Technology (ACT-05) program. The LNAs were also integrated in the airborne High Altitude MMIC Sounding Radiometer (HAMSR) that was developed under the IIP-98 and currently is funded to be installed onto the Global Hawk UAV for participation in NASA's Genesis and Rapid Intensification Processes (GRIP) hurricane field experiment in the summer of 2010.

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