A 180 GHZ PROTOTYPE FOR A GEOSTATIONARY MICROWAVE IMAGER/SOUNDER-GEOSTAR-III

Todd Gaier[1], Pekka Kangaslahti[1], Bjorn Lambrigtsen[1], Isaac Ramos-Perez[1], Alan Tanner[1], Darren McKague[2], Christopher Ruf[2], Michael Flynn[2], Zhengya Zhang[2], Roger Backhus[2], David Austerberry[2]
[1]Jet Propulsion Laboratory
Pasadena, CA USA
[2]University of Michigan
(todd.c.gaier@jpl.nasa.gov)

***Abstract*—GeoSTAR-III, a 180 GHz prototype for the Precipitation and All-weather Temperature and Humidity Sounder (PATH), is the culmination of a decade of technology development funding. The interferometric radiometer comprises 144 receivers operating from 165-183 GHz and utilizes a 192x192 input, ASIC based mixed signal correlator. The demonstration of this instrument raises the technology readiness of the radiometer subsystem to level 6 (TRL 6) and the correlator subsystem to TRL 5. We demonstrate the full functionality of this system with observations of the Sun and Moon as well as nearby thermally emissive objects. This represents the final milestones in the development effort of pre-mission technologies for this decadal survey mission.**

Keywords—geostationary microwave sounder, synthetic thinned aperture radiometer, cross-correlator

I. Introduction

The 2007 National Academies Decadal Survey (DS) on Earth Science [1] recognized that continuous observations of microwave temperature and humidity would play an important role in the for both physical interpretation and weather forecast modeling of highly dynamic weather systems. Concerns about the technical maturity, while recognizing the scientific promise of such a mission, motivated the study team to create the Precipitation and All-weather Temperature and Humidity (PATH) mission and place it in Tier 3 of the mission priority list. In response to the DS, NASA embarked on a decade-long technology development effort, funded through the Earth Science Technology Office (ESTO), to retire the technical risks associated with the PATH mission. A first effort, GeoSTAR-I [2], demonstrated the feasibility and calibration potential of such an instrument, operating at 60 GHz. A second instrument GeoSTAR-II, clearly demonstrated the ability to obtain similar performance at 180 GHz using compact "IC" style receivers using state-of-the-art InP monolithic microwave integrated circuit (MMIC) technology, but fell short of demonstrating the final technological piece of the puzzle; a low power, high bandwidth, correlator subsystem capable of processing the PATH intermediate frequency (IF signals). GeoSTAR-III set out to close this final gap and elevate the PATH mission technologies to TRL 6, paving the way for the development of this long-elusive observational gap. We report on the successful development of the GeoSTAR-III system, describe the subsystem development, subsystem *environmental testing* and *radiometric performance*, clearly demonstrating the maturity of this instrument technology at a scale approximating the final mission requirements.

II. GeoSTAR-III System

The GeoSTAR-III system (shown in Figure 1) comprises 144 receivers operating between 165 and 183 GHz. The receivers are arranged in 9 tiles of 16 receivers. Each receiver is fed by a profiled feed antenna, while each tile distributes the local oscillator (LO) signal via waveguide manifold at half the RF response frequency [3]. The receivers forming an in-phase /quadrature-phase (I-Q) superheterodyne network, utilize a miniature multi-chip integrated circuit, which is mounted on a printed circuit board providing IF amplification and DC bias functionality. IF signals are carried via 288 miniature coaxial cables to the correlation subsystem, for high-speed processing of the analog signals into 288*(287) products containing the visibility information of the observed scene.

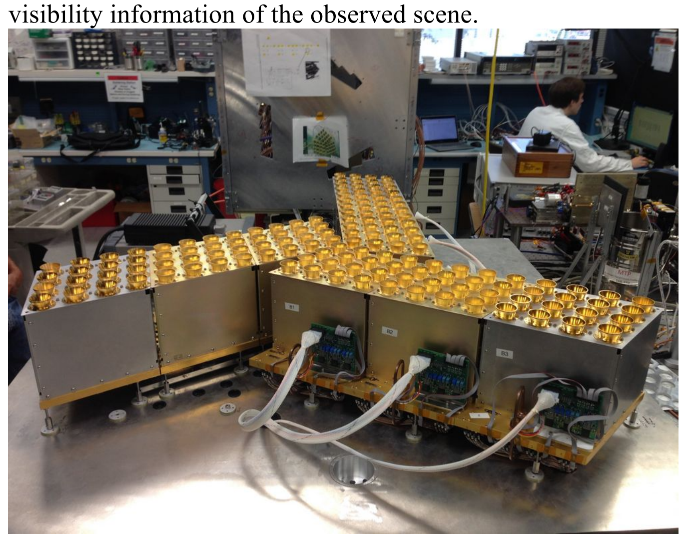

Figure 1. The GeoSTAR-III instrument comprising 144 receivers operating at 180 GHz with a CMOS-based correlator subsystem.

A. 183 GHz Receivers

The 183 GHz receivers for GeoSTAR-III have been described in detail in previous publications [4]. The block diagram and photograph of an example of one such receiver is shown in Figure 2. While no design changes were required for the receivers, successful development of 144 receivers operating at F-band required careful attention. For this effort , combination of robotic and manual assemble was employed to demonstrate that this approach is readily scalable to even larger arrays. From previous efforts, it was understood that detailed characterization of the gain and noise of the receivers is essential to the final array performance. Accordingly, an automated test-set was developed to simultaneously characterize amplitude and phase response as well as the noise of each receiver in a non-destructive configuration. The net result was a receiver yield of greater than 80% with performance of 10-15 dB gain and noise between 300-500 K.

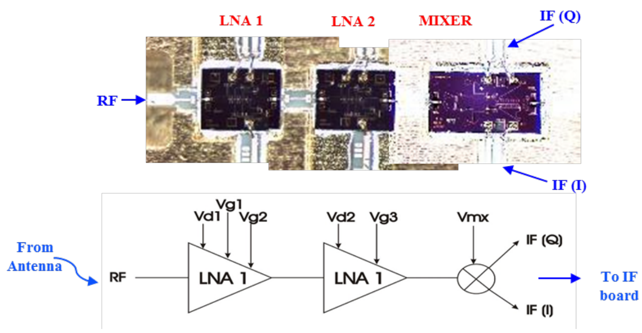

Figure 2 Block diagram of the MIMRAM module and photo of the assembly. Two low noise amplifier MMICs provide low noise and high gain, and the second harmonic I-Q mixer MMIC enables quadrature conversion to baseband with low LO power.

B. CMOS ASIC Analog-Digital Converter/Digital Correlator

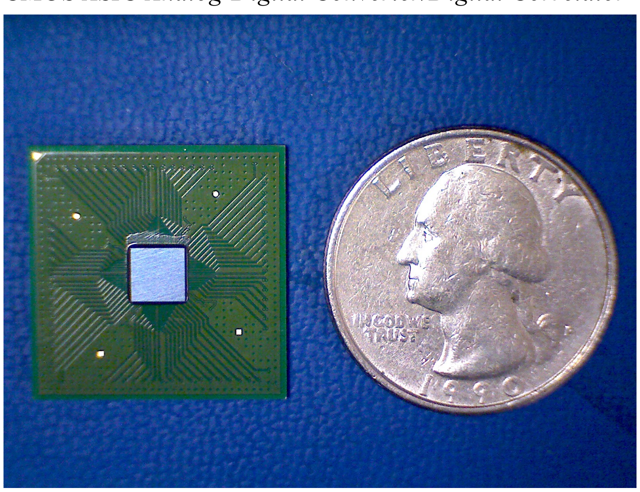

Figure 3 Packaged 64x64 A/D Correlator ASIC chip.

The sole outstanding technology at the outset of this effort was the correlation subsystem. Previous efforts demonstrated the instrument performance with FPGA and smaller ASIC correlators, but none were able to achieve the simultaneous bandwidth and power requirements for the larger mission. It was recognized early in this effort that integrating the A/D function with the digital correlation processing is necessary to meet the mission power consumption goals. Using 65 nm CMOS it was possible to realize a 2-bit, 64x64 input ASIC chip operating at 1 GHz clock rate (for a 500MHz bandwidth)[5]. The chip, shown in Figure 3, meets all of the performance and power requirements for the PATH correlation subsystem. Three chips were integrated into the GeoSTAR-III correlator subsystem (Figure 4) and subsequently integrated with the instrument.

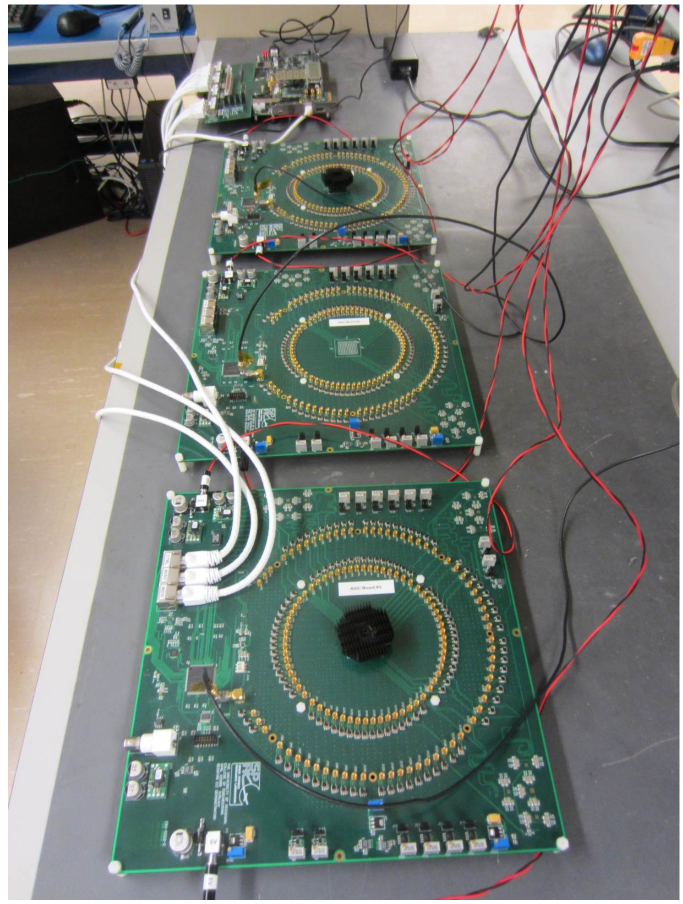

Figure 4. The correlation subsystem comprising 3 ASIC on boards and an FPGA-based readout circuit.

In order to raise the TRL of the array subsystems is was necessary to perform environmental testing on representative subassemblies. Thermal vacuum tests were performed on a partially populated tile. The tile was cycled over temperature from -40C to +60C with no anomalies observed. This test captured the MMICs, receiver modules, IF and bias circuits as well as the LO distribution.

It was also deemed necessary to perform vibration testing. This too was done on a representative manifold (excluding the feed horns which were not mechanically designed for that purpose). The random vibration testing, which captured the receiver modules, mechanical mounting to the PCB IF/Bias boards, PCB components and the manifold, showed no anomalies between before and after testing.

C. Instrument Integration

An Al honeycomb panel was fabricated to provide a mechanically and thermally stable support for the array. This optical bench, which was designed to provide stability to λ/16, was fabricated from two 0.030" face sheets separated by 1.5". The tiles are each kinematically mounted to the panel with three standoffs. Alignment of the tiles used "jigs" applied to the antenna apertures. LO distribution and phase switching were similar to GeoSTAR-II, but with modified distribution manifolds for each arm of the array. The correlator subsystem was mounted directly to the back of the panel.

III. Observational Results

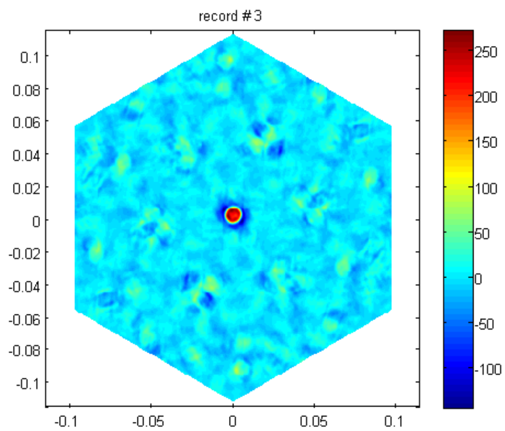

Figure 5."First light" observations of the sun. The image of the solar disk matches the anticipated image.

Tests of the full array proceeded with the setting of the A/D thresholds on the correlator ASICs. This was done to provide a uniform signal distribution with only the receiver noise as an input. Next, the system observed a source in the near-field to confirm that the correlator channels were functional. The system was then moved outdoors to observe the sun. The 'first light' performance (Figure 5.) appears to be excellent in that the visibility magnitude measured of the solar disk exhibits very good agreement with the Airy function versus baseline that one expects to observe. The synthesized image of the sun also matched the anticipated image very well—accounting for the fact that there are many known missing baselines which have not yet been filled. Finally, observations of the moon were performed and are shown in Figure 6.

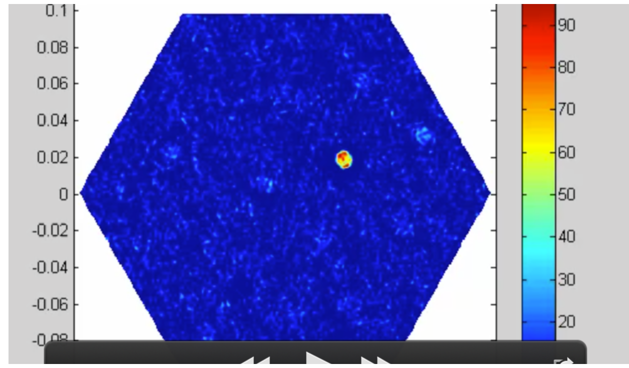

Figure 6. Uncalibrated, resolved image of the moon (clipped from time lapsed video)

IV. Summary

We have demonstrated the performance of a 144 element, 180 GHz synthetic aperture array receiver. The receiver employs a CMOS 64x64 input A/D –correlator chip in the correlation subsystem. The array subsystem underwent environmental testing to demonstrate TRL 6 while the entire system was used to perform observations of physical targets to demonstrate a total system TRL of 5 (6 when environmental tests of the correlation subsystem are completed). This advancement in TRL has prepared the GeoSTAR system to meet the requirements of the PATH mission.

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