GEOSTAR-II: A PROTOTYPE WATER VAPOR IMAGER/SOUNDER FOR THE PATH MISSION

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ABSTRACT

We describe the development and progress of the GeoSTAR-II risk reduction activity for the NASA Earth Science Decadal Survey PATH Mission. The activity directly addresses areas of technical risk including the system design, low noise receiver production, sub-array development, signal distribution and digital signal processing.

Index Terms— Synthetic Aperture Radiometry, MMIC receivers, digital correlators

1. INTRODUCTION

The PATH mission, described in the NASA Earth Science Decadal Survey [1] will provide continuous all-weather temperature and humidity sounding from geostationary orbit. The instrument requires imaging receivers with moderate spectral coverage about the 60 GHz oxygen line complex and the 183 GHz water line. The preferred concept to meet this requirement is an interferometric imager as it requires no moving parts and can synthesize the required large aperture. Following the successful GeoSTAR demonstration at 60 GHz [2], several technological challenges remain in the realization of system capable of 0.3 K retrievals with a resolution of 25 km at 183 GHz and 50 km at 60 GHz. NASA has funded the development of these key technologies in an Instrument Incubator activity at 180 GHz. The project will fabricate a 48 element receiver array operating at 165-183 GHz Key areas of technology development include the system architecture, receivers, multi-feed modules, IF amplifiers, low power phase switched local oscillators, low power high speed ASIC digitizers and digital cross-correlators.

2. GEOSTAR-II ARCHITECTURE

The GeoSTAR-II prototype is intended to develop and exercise all of the technologies required for a PATH mission. A design study carried out at the beginning of the project revealed several driving requirements. The design adopted purposely pushed many of these technologies to their extremes, in an attempt to straddle the as yet undefined mission requirements. By far the most stringent "requirement" is the recovery of brightness temperatures with a precision of 0.3 K in 15 minutes. This requirement forced a detailed reevaluation of the initial concept to maximize sensitivity.

2.1. Array Design

The GeoSTAR-II demonstrator consists of three, complete and self-contained "sub-array modules" of 16 elements each. This "sub-array" approach anticipates that a large spaceborne array, consisting of hundreds of receiver elements, will be most practical if it can be manufactured as a smaller number of such modules, or "tiles" to be assembled in the larger array during the latter stages of integration. Each element is a superheterodyne receiver with I and Q outputs. The local oscillator is common to all 16 elements of a sub-array module. The IF amplification and bias circuitry reside on boards mounted directly to the 16 element sub-array module. The IF signals are routed to a correlator unit on coaxial cables. The system is not designed to provide full imaging capability, but to demonstrate all of the elements needed to develop an imager.

2.2. Array Design

Examination of GeoSTAR-I revealed that much of the sensitivity was lost to regions of the field of view with poor inherent sensitivity and little scientific interest, namely high latitudes at high zenith angle.

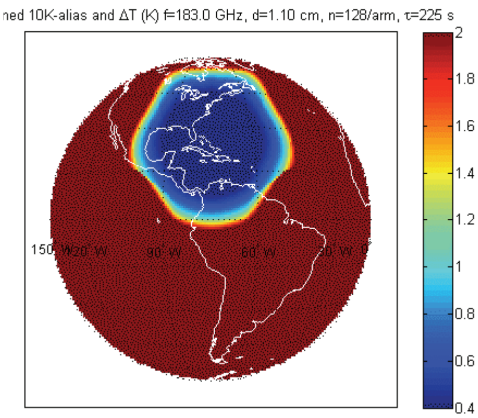

Figure 1. The new 4-row geometry improves the sensitivity in the primary science field of view.

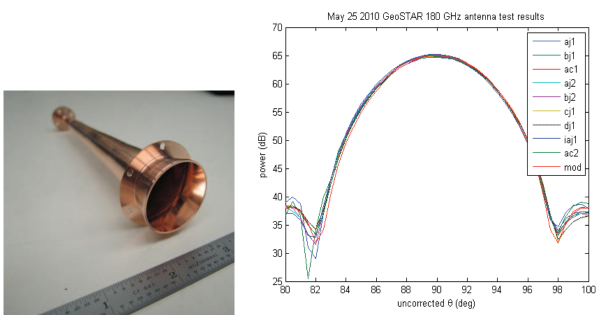

Figure 2. (left) Photograph of new feed horn (right) Measured beam pattern of feed.

Simultaneously reducing the field of view and cropping the primary beam pattern allowed re-spacing of the antennas [3]. Instead of the single row of antennas adopted in GeoSTAR, this version has 4-rows of antennas on a coarser grid. This dramatically improves the sensitivity in the desired field of view as shown in Figure 1. The feed horns, which provide this sensitivity, are shown in Figure 2 along with the measured beam pattern.

3. SUBSYSTEMS

The instrument is broke into four major subsystems; the compact low noise receivers, subarray modules, IF signal distribution and the digitizer/correlator.

3.1. Low Noise Receivers

The low noise receivers comprise two low noise amplifiers and a second harmonic I/Q mixer [4]. Each of these devices is fabricated on a 35 nm InP HEMT process [5], yielding excellent noise and bandwidth. The chips are mounted in an SOIC style flat-pack with waveguide ports for the signal and LO inputs (Figure 3). The 10-500 MHz IF is carried on the package leads along with the bias signals. The noise performance of the modules is shown in Figure 4.

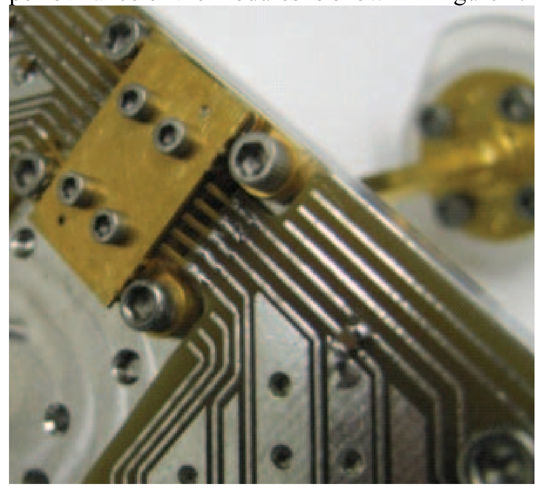

Figure 3. Compact low noise receiver module.

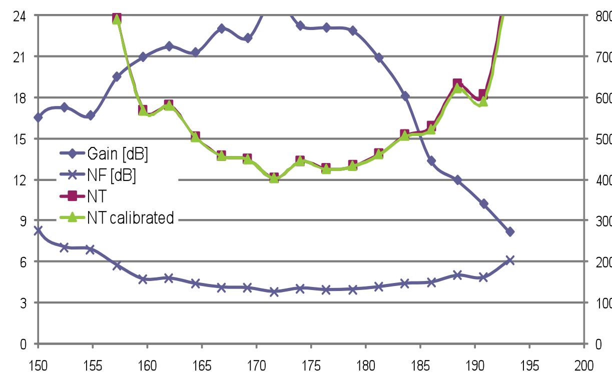

Figure 4. Gain and noise performance of receiver module.

3.2. Sub-Array Modules

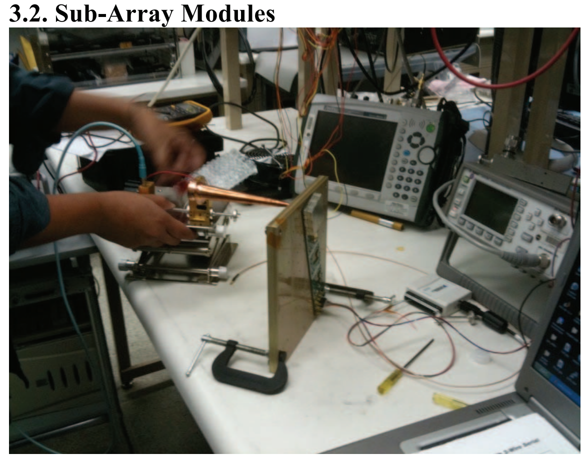

Figure 5. Partially populated sub-array module on the bench during testing.

To facilitate the integration of the larger system, the receiver elements are mounted on a sub-array module of 16 elements. The module provides structural support for the antennas and receivers as well as LO and IF distribution. The antennas are mounted to a manifold with integral polarizers allowing the receiver modules to be mounted on the back. The manifold divides and distributes the LO with equal phase and amplitude. The LO itself is derived from a tunable phase locked YIG oscillator which is multiplied (x6) to W-band. At the second harmonic, the signal is phase switched with 5-bit precision and amplified. A photograph of the partially populated module is shown in Figure 5.

3.3. IF Signal Distribution

The 10-500 MHz IF signal requires 40 dB of gain prior to digitization. The IF subsystem was designed to provide gain with low power consumption and low mass (the nominal PATH system has more than 700 such signals). The amplifiers utilize surface mount Si bipolar transistors in a very simple circuit. Isolation between channels is provided by shielding grounds and via holes along with metal cans soldered to the board in sensitive locations. The run from the IF board to the digitizer/correlator uses RG-178 coaxial cable and SMP connectors.

3.4. ASIC Digitizers and Correlators

The correlator is the most challenging technology required for the PATH mission. Utilizing FPGA technology would limit the bandwidth and require more than 2KWfor PATH. We have developed a small demonstration correlator sized for this array using 90 nm CMOS ASIC technology. The chip was designed to accommodate 19x19 inputs and demonstrate 250 uW/correlation at 500 MHz bandwidth (or 450 W for the full system). Using the same device technology, we developed a 2-bit 750 MSPS analog to digital converter, which consumes 30 mW of power, a factor of 30 reduction in what is available commercially.

5. CONCLUSION

We have described a technology risk reduction activity for the PATH mission. The GeoSTAR-II effort addresses the areas of array architecture, low-noise front-ends, rational sub-array integration, signal distribution and cross-correlation. The resulting subsystems will be used to evaluate the proposed PATH mission architecture and performance.

5. ACKNOWLEDGEMENTS

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