ENABLING THE NASA DECADAL-SURVEY "PATH" MISSION

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ABSTRACT

In its "Decadal Survey" of earth science missions for NASA published in 2007 [1] the U.S. National Research Council (NRC) recommended that a geostationary microwave sounder be developed for a Precipitation and All-weather Temperature and Humidity (PATH) mission and recommended that it be implemented as an "array spectrometer". That was largely based on a synthetic-aperture concept then under development at the Jet Propulsion Laboratory (JPL). At the time the required technology was not perceived as being sufficiently mature, and PATH was therefore put in the "third tier" group of missions. Now, under the NASA Earth Science Technology Office's (ESTO) Instrument Incubator Program (IIP), the key technology has been developed and has been brought to Technology Readiness Level (TRL) 6, required for mission implementation, thus enabling the PATH mission.

Index Terms— Microwave, geostationary, atmospheric sounder, aperture synthesis, severe storms

1. INTRODUCTION

It has long been recognized that a geostationary microwave (GEO MW) sounder would be a powerful tool for weather prediction. Microwave sounders have operated on polar-orbiting low earth orbit (LEO) satellites since the 1970's and have had the largest impact on weather forecast accuracy of all the satellite sensors. This is because they measure the thermodynamic state of the atmosphere even in the presence of clouds, which allows dynamic weather processes to be captured. The assimilation of data from more and more such sensors has resulted in steadily improved forecast accuracy. However, polar-orbiting LEO satellites will at best pass over a given scene only twice in 24 hours, and that means that the most rapidly evolving phenomena, such as severe storms and tropical cyclones, are poorly sampled and therefore often poorly predicted, particularly in terms of intensity. A sensor operating in geostationary orbit would overcome that obstacle, typically being capable of observing repeat cycles of mere minutes.

2. PATH MISSION OBJECTIVES

The goal of the PATH mission is to improve the understanding, modeling and prediction of severe storms and similar phenomena, including dynamic water vapor transport processes such as monsoons and atmospheric rivers. Thus, the PATH mission can be viewed as a mission to monitor the dynamic aspects of the hydrologic cycle in the atmosphere [3]. For NASA the main emphasis is on research, i.e. to gain a better understanding of the underlying processes, followed by model improvements. For NOAA and other operational agencies the emphasis is on assimilating the observations into forecast models and generate better forecasts, which requires both improved models and better observations.

3. MEASUREMENT REQUIREMENTS

The fundamental requirement is for the PATH sensor to provide temperature and water vapor sounding (i.e. generate vertical profiles) continuously, with a very rapid update cycle (15-30 minutes) and under nearly all weather conditions. The spatial resolution must be sufficient to resolve key storm processes. Past research based on data from LEO sounders, such as the Advanced Microwave Sounding Unit (AMSU), suggests that this can be achieved with the capabilities of those sensors if they were available in GEO. Thus, the PATH sensor can be viewed as "AMSU in GEO". This requires operating in the 50- or 118-GHz band for temperature sounding and in the 183-GHz band for water vapor sounding, as noted by the NRC. It also means attaining spatial resolution of about 25 km (similar to the 15-50 km of AMSU). Such a resolution is very difficult to achieve with a microwave sensor in GEO and has prevented the development of a GEO MW system until now. For example, AMSU has an antenna aperture of about 15 cm, but scaled from LEO (830 km) to GEO (36,000 km) this becomes 6.5 m. Getting such an antenna into space while maintaining the surface precision required for sounding has been prohibitive, and scanning it across the earth disc is also a show stopper. This problem has now finally been solved with the development of the Geostationary Synthetic Thinned Aperture Radiometer (GeoSTAR) design and the technology required to implement it.

4. THE GEOSTAR CONCEPT

GeoSTAR is a microwave sounder concept first proposed in 1999 [4] for the NASA New Millennium program. It is based on synthesizing a large antenna aperture. In essence, a large but sparse array of small antennas is used as a spatial interferometer that samples the spatial fourier spectrum of the radiometric field. This is illustrated in Figure 1. Each pair of receivers in the antenna array (upper-left) acts as an interferometer that samples a point in the 2-dimensional fourier space (upper-right), often called the uv-space. When viewing a radiometric image (lower-left), the cross-correlation between a receiver pair is a measure of the magnitude and phase of the matching fourier component of the image, and that results in a fourier image (lower-right). An inverse fourier transform then recovers the radiometric image (lower-left). This principle has been proven in radio astronomy as well as in the Soil Moisture and Ocean Salinity SMOS) space mission. The primary advantages of such a STAR system are that a large aperture can be formed with an array that can be folded during launch, is more efficient than a real-aperture system, and requires no scanning.

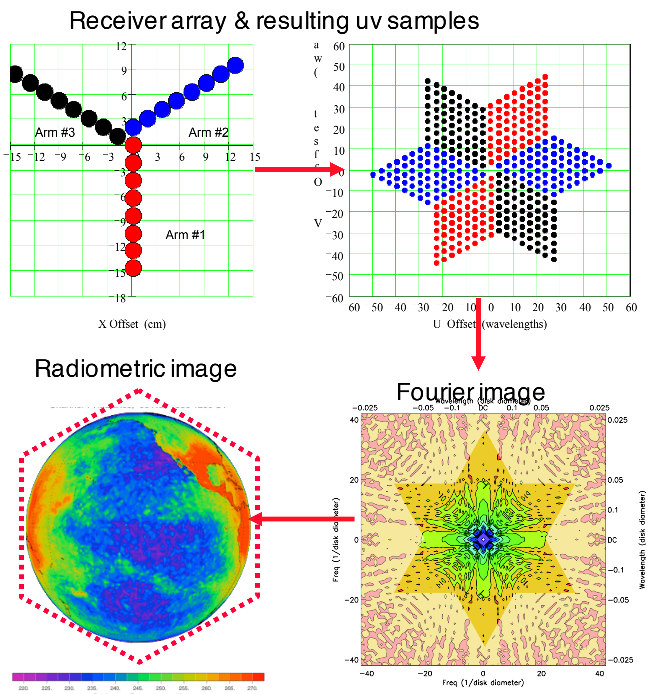

Figure 1. Basis for aperture synthesis radiometry

5. TECHNOLOGY DEVELOPMENT

The GeoSTAR concept and technology were developed under three consecutive IIP efforts between 2003 and 2015. In GeoSTAR-I (2003-2006) a proof-of-concept prototype operating in the 50-GHz band was built and used to demonstrate the feasibility of the concept. It was established that the system can be well calibrated and is inherently extremely stable and fault tolerant. GeoSTAR-II (2008-2011) was used to develop compact, low-power receivers and an antenna array design that makes it possible to limit the overall field of view and greatly improve the antenna efficiency and thus the radiometric sensitivity, and to demonstrate imaging at 183 GHz. Finally, GeoSTAR-III (2011-2015) was used to develop a low-power cross-correlator integrated circuit. A complete end-to-end system has been built, and key components and subsystems have undergone environmental testing to validate TRL 6.

5.1. The GeoSTAR instrument design and technology

Figure 2 shows the architecture of GeoSTAR-III. It consists of three arms of 4x4 antenna array submodules, and each of the 16 elements consists of a small feedhorn and an integrated-circuit receiver. A block diagram of a receiver is shown in the upper-left. The key technology elements are the receivers, the antenna array modules, the correlator, and the local-oscillator (LO) subsystem. In the following sections we briefly touch on each of them.

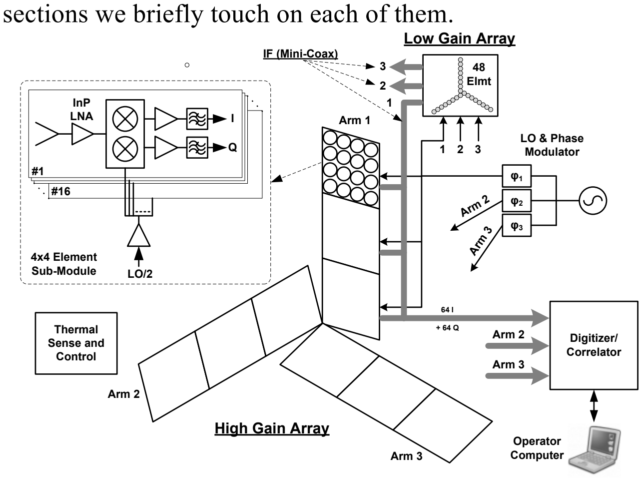

Figure 2. GeoSTAR-III architecture

5.1.1. Receivers

The receivers consist of monolithic microwave integrated circuits (MMIC), called MIMRAMs and operating between 160 and 200 GHz with a noise temperature between 300 and 500 K. Figure 3 shows a photo of a receiver mounted on a circuit board.. Each weighs less than 3 g and consumes 25 mW.

Figure 3. MIMRAM receiver

5.1.2. Antenna array

Figure 4 shows a photo of the complete GeoSTAR-III array of 9 4x4 tiles. The feedhorns are embedded in a structure that ensures mechanical alignment and stability. In a space system heat pipes along the baseplate of the array will ensure similar stability even in the severe thermal environment encountered in space.

Figure 4. GeoSTAR-III antenna array

5.1.3. Correlator

Figure 5 shows three correlator boards (one for each array arm). The correlator ASIC sits in the center of each board. It is capable of correlating 64 pairs of IF signals at a clock speed of 1 GHz and has on-board digitizers and totalizers. The chip itself is 4.2 mm square and sits on a 2.1 cm chip carrier that connects to the circuit board via a 576-element ball grid array. The correlations are determined as 2-bit multiplications. At 1 GHz it achieves more than 6 trillion multiplications per second, at a power consumption of 2.5 W (i.e. 0.6 mW per correlator).

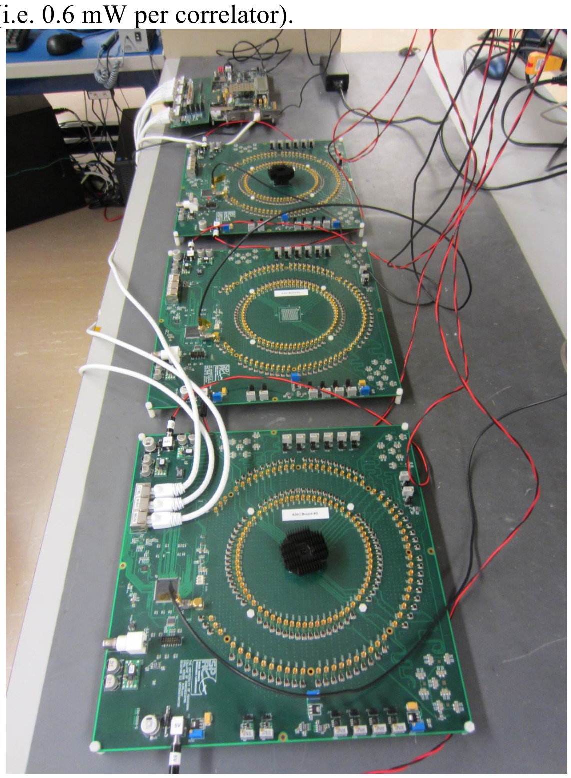

Figure 5. Correlator boards

5.1.4. Testing

Figure 6 shows an image of the (new) moon obtained with the complete GeoSTAR-III system. In addition to such end to end system tests, the key technology components or subsystems have also undergone environmental testing to verify TRL 6. That includes radiation testing of the correlator chip design, vibration testing and thermal-vacuum testing. All test results indicate that PATH can now proceed.

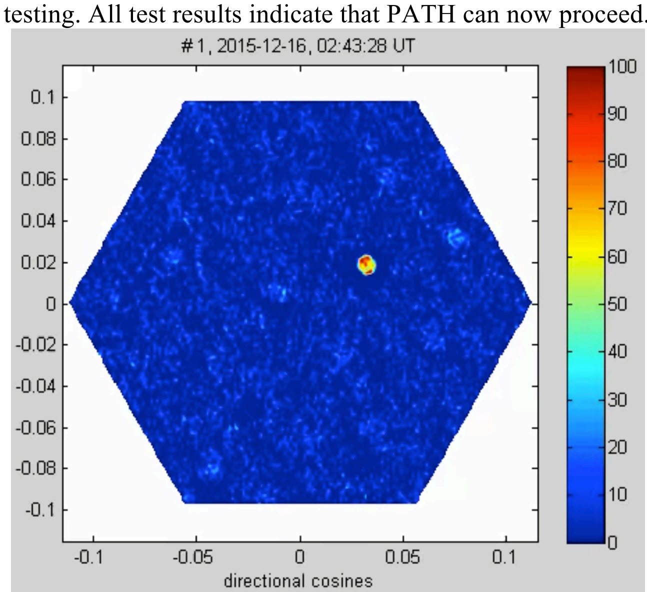

Figure 6. Image of the new moon from GeoSTAR-III

6. CONCLUSION

JPL, with the help of the University of Michigan, has succeeded in developing all of the key technology required to implement the PATH mission. All elements are now at TRL 6 or higher.

11. REFERENCES

[1] R. Anthes and B. Moore, eds., *Earth Science and Applications from Space—National Imperatives for the Next Decade and Beyond*, National Academies, Washington, DC, 2007

[2] T. Gal-Chen, B. Schmidt, and L. Uccellini, "Simulation Experiments for Testing the Assimilation of Geostationary Satellite Temperature Retrievals into a Numerical Prediction Model," *Mon. Wea. Rev.*, 114, pp. 1213-1230, 1986.

[3] B. Lambrigtsen et al., "Monitoring the Hydrologic Cycle with the PATH mission," *Proc. IEEE*, vol. 98, pp. 862-877, 2010.

[4] B. Lambrigtsen, "GEO/SAMS – The Geostationary Synthetic Aperture Microwave Sounder," *Proc. IGARSS'00*, 2984-2987. Doi:10.1109/IGARSS.2000.860310. 2000