Initial Images of the Synthetic Aperture Radiometer 2D-STAR

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***Abstract*—Initial results are presented for the new synthetic aperture radiometer, 2D-STAR, which is a dual-polarized L-band radiometer that employs aperture synthesis in two dimensions. This airborne instrument is the natural evolution of the Electronically Scanned Thinned Array Radiometer, which employs aperture synthesis only in the across-track dimension, and represents a further step in the development of aperture synthesis for remote sensing applications. 2D-STAR was successfully tested in June 2003 and, then, participated in the SMEX03 and SMEX04 soil moisture experiments. A description of the instrument and initial results in the form of first images and a preliminary comparison with changes in soil moisture during SMEX03 are presented here.**

***Index Terms*—Aperture synthesis, microwave radiometry, remote sensing, soil moisture.**

I. Introduction

PASSIVE microwave remote sensing at long wavelengths offers the potential for monitoring parameters of the Earth surface such as soil moisture, ocean salinity, and sea surface temperature that are important for understanding energy exchange at the surface and, therefore, are important for improving understanding of weather and climate change. However, long wavelengths require large antennas in orbit, and this requirement has limited the resolution obtainable from space. In particular, soil moisture, which is a primary component of the hydrologic cycle, is not currently being measured from space at L-band because of the large antennas needed to achieve adequate spatial resolution. For example, to obtain a resolution of even 10 km at 1.4 GHz (L-band) for monitoring soil moisture with a radiometer would require an aperture on the order of 20 m at an altitude of 800 km.

One approach to address this problem is an interferometric technique called aperture synthesis [1], [2]. This is an adaptation of a technology developed originally in radio astronomy in which the resolution of a single large aperture is obtained using an array of small antennas and signal processing [3]. The technique has been successfully applied to Earth remote sensing in the form of an L-band radiometer called the Electronically Scanned Thinned Array Radiometer (ESTAR) [4]–[6]. However, ESTAR employs synthesis in only one dimension (across track) and uses conventional antenna technology (dipole arrays) to obtain a resolution along track. This hybrid configuration has advantages (e.g., fewer correlators and a direct relationship between polarizations defined at the sensor and on the surface); however, it limits the amount of array thinning possible and flexibility in choosing the configuration of the array [1].

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A next-generation synthetic aperture radiometer has been developed to demonstrate the potential of aperture synthesis in two dimensions for remote sensing applications such as monitoring soil moisture. The instrument, which is called 2D-STAR, was developed under the National Aeronautics and Space Administration's (NASA) Instrument Incubator Program under a partnership between the Goddard Space Flight Center (GSFC), the University of Massachusetts (antenna design), and Prosensing (receivers, digital processing and building the hardware). It represents a next step in the development of the technology and is the natural successor to ESTAR. It also represents the radiometer technology that is employed in the Soil Moisture and Ocean Salinity (SMOS) mission being developed by the European Space Agency [7]. The instrument was first tested in 2002. In the summer of 2003, it participated in the SMEX03 soil moisture field campaign flying research sites in Alabama (AL), Georgia (GA), and Oklahoma [8], and in the summer of 2004, it participated in SMEX04 in Arizona and Mexico [9].

The objective of this paper is to present first results with the 2D-STAR instrument. In particular, this paper will present examples of the first images from the new instrument and a qualitative comparison of the radiometer data with changes in soil moisture. A detailed comparison with surface data is underway. In the sections to follow, a description of the instrument is presented, and then, images are shown from a test flight in the vicinity of NASA/GSFC Wallops Flight Facility and from flights at the Huntsville, AL and Tifton, GA, sites in SMEX03 during which changes in soil moisture occurred. The images show that the 2-D synthetic aperture radiometer responds to the dominant features of the test sites and the changes in soil moisture.

II. 2D-STAR Instrument

The 2D-STAR instrument was developed as a research instrument with the flexibility to test options in the evolution of the technology as it existed in ESTAR (synthesis in one dimension, one polarization, and analog processing) to aperture synthesis in two dimensions, dual polarization, and digital processing. The 2D-STAR was designed to fly on a P-3 research aircraft (the NASA Orion P-3B), and to simplify installation, the size was chosen to be similar to that of ESTAR. Several options, such as the choice of the antenna array and number of bits in the digital processor, were made to accommodate potential research rather than efficiency of design. The general characteristics of the instrument are summarized in Table I and described in more detail below.

Fig. 1 shows a block diagram of the 2D-STAR instrument. The antenna consists of an array of 21 dual-polarized patch antennas. Behind each antenna element is an analog receiver that

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TABLE I
INSTRUMENT PARAMETERS

Antenna Array	
Dimensions	1.25 m x 1.25 m
Number of elements	11 x 11
Element spacing	0.5 λ
Individual elements	
Type	Dual polarized patch
Beam width	60 deg FWHM
RF	
Center frequency	1.413
BW	24 MHz
Polarization	Dual pol – switched
Integration (per sample)	10 ms
Correlator	Digital, 8 bits
Image	
Synthesized beam width	
Individual snapshot	9 deg FWHM
Smoothed	15 deg FWHM
Integration /snap shot	0.1 sec
Time between snap shots	0.2 sec
Polarization	(Tv + Th); Tv; Th

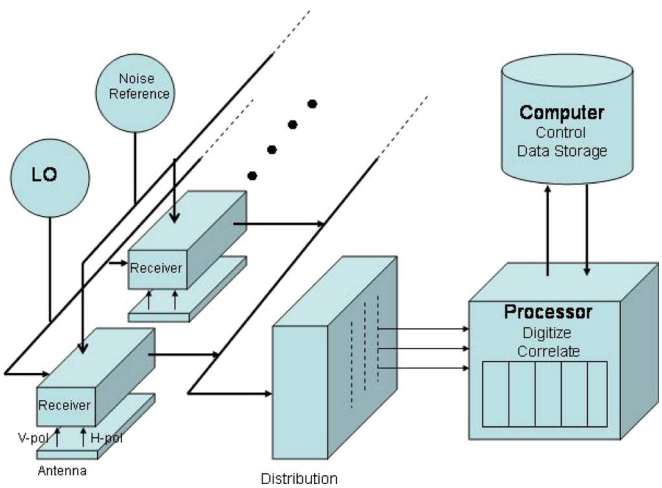

Fig. 1. Block diagram of the 2D-STAR instrument. The equipment is configured to fly on the NASA P-3 aircraft. Functions to the left of the "Distribution" block are contained in the "RF box" which is located in the aircraft bomb bay, and the other functions belong to equipment housed in racks and located in the aircraft cabin.

amplifies and filters the RF antenna signal and mixes it to the intermediate frequency (IF). In normal operation, the receiver switches between the two polarizations, but the switching is controlled by a microprocessor, and it can also operate in a single-polarization mode. The receivers are fed with a common local oscillator signal and, also, a reference noise signal which is used for calibration. The IF output goes to an analog distribution box where the signal from each antenna–receiver is divided into six signals. These signals $(6 \times 21 = 126)$ go to the processor where they are digitized, and the complex correlations from all antenna pairs are formed. The operation is controlled by the computer that also stores the output of the processor. The antenna array and receivers are contained in an "RF box" that is mounted in the bomb bay portion of the aircraft. The distribution box, signal processor, computer controller, and power supplies are mounted on racks inside the aircraft cabin. These are connected to the RF box by coaxial cables for the IF signals and cable bundles for power and control lines.

Fig. 2. 2D-STAR RF box. (Top) Antenna array with the radome removed to show the array of L-band patch antennas. (Bottom) View from the rear showing the " + " configuration and the receivers mounted behind the array of patches on the principle axes.

Fig. 2 (top) is a photograph of the RF box with the radome (the white structure on the left), removed to show the elements of the antenna array. The antenna consists of a fully populated 11×11 array of patches. Each patch is square and about 6.86 cm on a side. The patches are dual-polarized and separated by 0.5 wavelength (10.6 cm at L-band). The two polarizations are aligned with the principal axes of the array. In normal operation, they are oriented along track (X-pol) and across track (Y-pol). For points in the image along the ground track, X-pol corresponds to vertical polarization and Y-pol corresponds to horizontal polarization. For points in the across-track direction, X-pol corresponds to horizontal polarization, and Y-pol to vertical polarization. For points at other azimuths in the field of view, the instrument polarizations are linear combinations of horizontal and vertical polarizations.

VII. CONCLUSION

Initial images from the new synthetic aperture radiometer 2D-STAR have been presented. This instrument represents the next step in this technology, extending synthesis to two dimensions and to dual polarization. Synthesis in two dimensions offers the promise of new remote sensing options such as obtaining data over a wide range of incidence angle (and azimuth) and options for advanced retrieval algorithms. The research with 2D-STAR is designed to address these issues and to help realize the full potential of synthesis in two dimensions. The evidence presented here is a step toward those goals.