Development of the Synthetic Aperture Radiometer ESTAR and the Next Generation

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Abstract —ESTAR is a research instrument built to develop the technology of aperture synthesis for passive remote sensing of Earth from space. Aperture synthesis is an interferometric technology that addresses the problem of putting large antenna apertures in space to achieve the spatial resolution needed for remote sensing at long wavelengths. ESTAR was a first step (synthesis only across track and only at horizontal polarization). The development has progressed to a new generation instrument that is dual polarized and does aperture synthesis in two dimensions. Among the plans for the future is technology to combine active and passive remote sensing.

Keywords—Microwave; Remote Sensing; Passive; L-band; Aperture Synthesis

I. INTRODUCTION

ESTAR was built to demonstrate the potential of aperture synthesis for remote sensing from space at the long wavelengths needed to monitor soil moisture and ocean salinity. The initial goals were to demonstrate that images could be made and calibrated from an aircraft. In the process, ESTAR has produced successful maps of soil moisture in experiments such as Washita92 and the Southern Great Plains Experiments in 1997 and 1999 and maps of sea surface salinity in experiments such as the Coastal Current Experiment (1993) and Gulf Stream Experiment (1999). ESTAR was a first generation instrument employing synthesis in only one dimension (across track) and one polarization (horizontal). A new instrument, 2D-STAR, has been built that is dual-polarized and does aperture synthesis in both dimensions (along track and across track). However, research with ESTAR continues. The current research includes new applications such as monitoring biomass and the potential synergy to be obtained by combining passive (radiometer) and active (scatterometer) measurements at L-band.

ESTAR and the research on aperture synthesis has been a partnership between the Goddard Space Flight Center and the University of Massachusetts. Among the students at the University who have contributed are A. Tanner, C. Ruf, A. Griffis, P. Gaiser and J. Isham. Keith Carver was a partner in the development of 2D-STAR and Prosensing has provided engineering expertise for both instruments. This paper presents a brief review of the research with ESTAR and a glimpse at the new work underway with the 2D-STAR.

II. ESTAR

Aperture synthesis is an interferometric technique in which the complex correlation of the signal from pairs of antennas is measured and the image itself is obtained via signal processing [1, 2]. It addresses the problem of putting large antenna apertures in space to achieve the spatial resolution needed at long wavelengths (e.g. L-band for remote sensing of soil moisture or ocean salinity) or from high orbits (e.g. temperature profiles at 50-60 GHz from geosynchronous orbit). Aperture synthesis has the advantage of covering a large field-of-view without mechanical scanning and the advantage of employing sparsely filled apertures for ease of deployment. There are many ways in which this technique can be employed for microwave remote sensing of the earth from space [2, 3]. The configuration adopted for ESTAR (Fig. 1) is a hybrid of a real and a synthetic aperture. It is a configuration that is viable in space [4] and involves relatively simple processing. Several examples are described in Le Vine [3].

In the hybrid configuration, conventional antennas are used to obtain resolution along track and aperture synthesis is used across track (Fig 1). The conventional aperture antennas in ESTAR are linear arrays of horizontally polarized dipoles with the long axis in the direction of motion. ESTAR has five linear arrays (eight dipoles each) spaced at integer multiples of 0.5 wavelengths. The antenna array with the radome removed is shown in Le Vine, et al [5, Figure 3]. Details of the instrument and processing and a brief history of the development are available in the literature [5, 6].

Figure 2 is an example of one of the first calibrated ESTAR images [5]. This is data collected during experiments at the USDA watershed at Walnut Gulch, AZ in 1991[7]. The top image is an ESTAR map of the study area before a thunderstorm wetted the western two-thirds of the watershed and the bottom image is the ESTAR map made after the thunderstorm. The differences are consistent with the rain pattern and with measurements made with the real aperture, pushbroom microwave radiometer (PBMR) which flew under similar conditions at the site the year before.

Since then, ESTAR has participated in successful soil moisture campaigns at the Little Washita Watershed in 1992 [8] and in central Oklahoma during the Southern Great Plains experiments in 1997 and 1999 [9, 10]. It also has contributed to the development of passive microwave remote sensing of sea surface salinity. Among its contributions are experiments demonstrating the potential of L-band for this application in experiments such as the Delaware Coastal Current experiment [11] and the Gulf Stream Experiment [12]. Figure 3 is an example, showing a comparison of salinity retrieved from the ESTAR measurements of brightness temperature with surface measurements by the research vessel, Cape Henlopen, during the Gulf Stream Experiment [12]. ESTAR is aging but has been refurbished relatively recently and was scheduled to fly in experiments as recently as November, 2003 (soil moisture and ice experiments that had to be postponed because of aircraft issues).

III. 2D-STAR

ESTAR is first generation instrument that employs aperture synthesis only across track and only at horizontal polarization. A next-generation instrument has been developed that is dual polarized and does aperture synthesis in both dimensions (along track and across track). This instrument, called 2D-STAR, was developed under NASA's Instrument Incubator Program. The development was a partnership between the Goddard Space Flight Center, the University of Massachusetts and Prosensing. The instrument made its maiden flight in 2002 and participated in its first field campaign in the summer of 2003 flying research sites in Alabama, Georgia and Oklahoma during SMEX-03.

Figure 4 shows the RF box of the 2D-STAR looking at the antenna array with the radome removed. A fully populated, rectangular array of patches was built. However, only elements in a subset of patches (a selectable configuration) are actually connected to a receiver. For example, the instrument can operate as a thinned array in the shape of a cross, "+" by selecting only elements along the principle axes. This is its current configuration. A fully populated array was built so that different configurations could be tried and to minimize effects of mutual coupling [13] by providing a similar environment for each patch.

2D-STAR is also dual polarized (ESTAR operates at horizontal polarization only). This is accomplished by rapidly switching between the two (orthogonal) polarization ports at each of the patches. Large cavity filters are used to suppress RFI and an internal noise diode and matched load are used for amplitude and phase calibration. The signals are mixed to IF in the receivers and then sent to correlators where they are digitized and the I-Q products formed. The RF processing is housed in the box shown in Figure 4 with the receivers located behind the antenna plane. Figure 5 shows the remainder of the instrument mounted in racks inside the NASA P-3 as it looked during SMEX-03. The digital correlators are mounted in the VXI cage in the center on the right. At the bottom right, is a distribution box which divides the signal from each antenna so that the appropriate pairs can be formed for multiplication (the function of the cable bundles).

Among the initial results obtained with the 2D-STAR instrument are a comparison of the impact of RFI on one- and two-dimensional aperture synthesis [14] and a first image made from data collected during a check flight over the Delmarva Peninsula [15]. Figure 6 shows a total power image made during the test flight over the Delmarva conducted prior to the departure for SMEX-03 in June, 2003. Preliminary images in vertical and horizontal polarization have been made and work is under way to verify calibration.

IV. CONCLUSION

The research with ESTAR has moved the technology of aperture synthesis a long way toward meeting the needs of the remote sensing community. Much work remains to be done. Synthesis in two dimensions offers the promise of the most aperture thinning and additional remote sensing options such as imaging in the equivalent of a conical scan (at multiple incidences angles simultaneously) and the availability of data as a function of incidence angle for use in advanced retrieval algorithms. But these possibilities need to be demonstrated. The research with 2D-STAR is designed to address these issues and to help realize this potential. The image in Figure 6 is an indication that the goals are attainable. And others are working on similar goals. An airborne instrument is under development at the Helsinki University of Technology [16] and SMOS will soon provide a demonstration of the potential of aperture synthesis in space [17].

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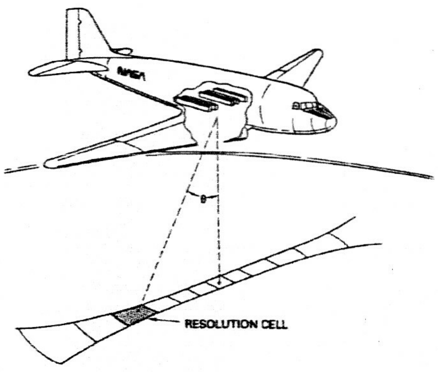

Figure 1. The hybrid real-and-synthetic aperture configuration adopted for ESTAR

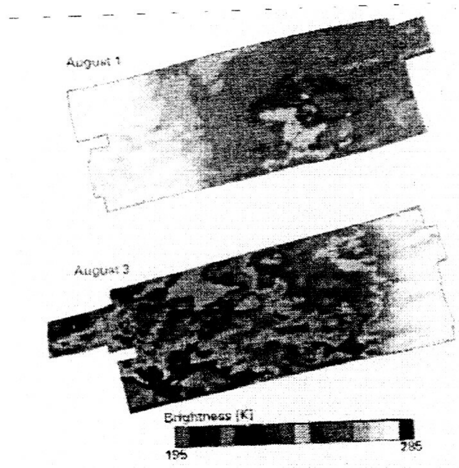

Figure 2. ESTAR brightness temperature image of the Walnut Gulch watershed made during calibration and validation tests in 1991.

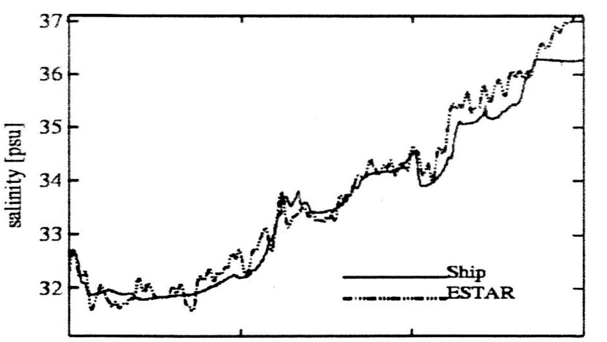

Figure 3. Comparison of salinity retrieved from ESTAR measurement of brightness temperatures compared with salinity measured by the R/V Cape Henlopen during the Gulf Stream experiment

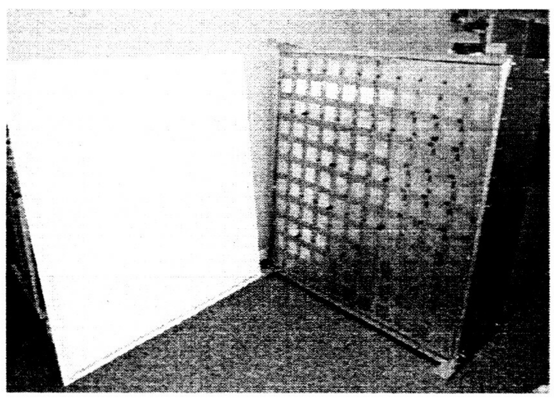

Figure 4: The antenna array for 2D-STAR showing the patch array with the radome (left) removed.

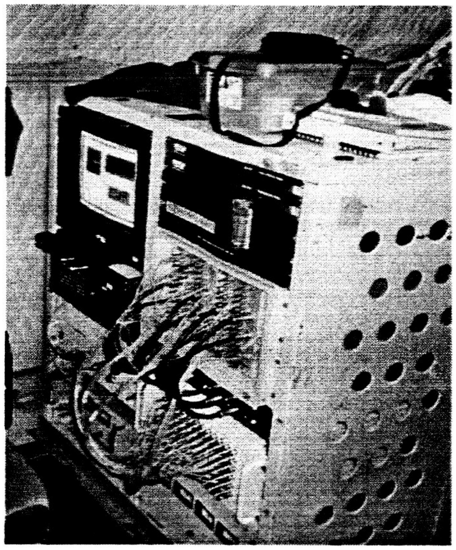

Figure 5. The 2D-STAR instrumentation rack as it appeared installed in the NASA P-3 during the SMEX-03 field campaign.

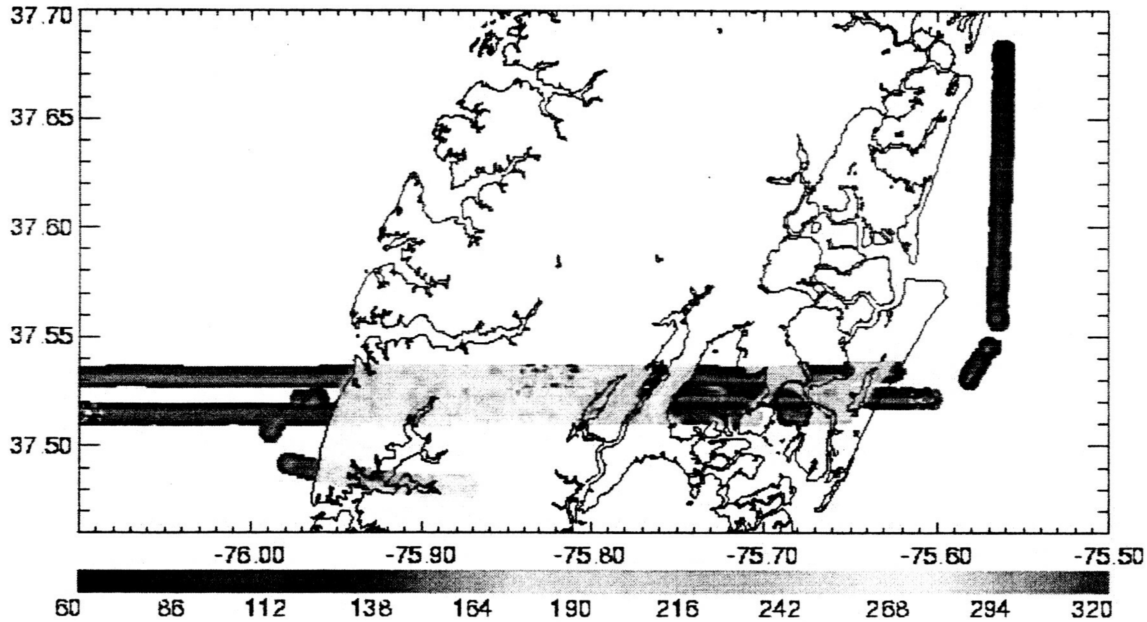

Figure 6: 2D-STAR image made over the Delmarva Pennisula south of the Wallops Flight Facility. The data was collected during a validation test flight in June, 2003 prior to departing for the SMEX-03 campaign. The flight consisted of three parallel east-west flight lines from the Atlantic Ocean (right) to the Chesapeake Bay (left). This is a total power image (sum of horizontal and vertical polarization) and is over a region mapped by ESTAR during its validation flights [6]. The red in the image is RFI [14].