KA-BAND SAR INTERFEROMETRY STUDIES FOR THE SWOT MISSION DEVELOPMENT

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***Abstract*. The primary objective of the National Research Council (NRC) Decadal Survey recommended SWOT (Surface Water and Ocean Topography) Mission is to measure the water elevation of the global oceans, as well as terrestrial water bodies (such as rivers, lakes, reservoirs, and wetlands), to answer key scientific questions on the kinetic energy of ocean circulation, the spatial and temporal variability of the world's surface freshwater storage and discharge, and to provide societal benefits on predicting climate change, coastal zone management, flood prediction, and water resources management. In this paper, we present the overall concept of the SWOT mission, as well as the scientific rational, objectives and development status of the technology items currently under development.**

***Index Terms*—** Altimetry, Synthetic Aperture Radar

I. INTRODUCTION

Radar altimetry has been a major achievement in the study of the Earth. Through the missions of TOPEX/Poseidon (1992-2005), and its follow-on Jason (2001-present), and the Ocean Surface Topography Mission (OSTM)/Jason-2 (2008-), a 15+ year data record of the global ocean surface topography has been obtained, which will extend into the future. However, the spatial resolutions of these missions are not sufficient to address fundamental scientific questions such as: (1) the eddy currents of the ocean that contains 90% of the kinetic energy of ocean circulation, and (2) the variability of water storage and discharge over land, which is key to achieve understanding of the global water cycle. SWOT will use a new technique to measure water elevation that will provide an order-of-magnitude improvement in resolution and accuracy that is required to address these scientific questions and to further our current knowledge of oceanography and land hydrology, while establishing a reference standard for future radar altimetry missions.

II. SWOT CONCEPT

The core technology for SWOT is the KaRIN instrument, originally developed from the efforts of the Wide Swath Ocean Altimeter (WSOA) [1], [2]. The KaRIn instrument (see Figure 1) will be complemented with the following suite of instruments: a Ka-band interferometer, a dual-frequency nadir altimeter, and a multi-frequency water-vapor radiometer dedicated to measuring wet tropospheric path delay to correct the radar measurements. The interferometer's concept is as follows: radar pulses are transmitted from each antenna, and the radar echoes from each pulse are received by both. The interferometric phase difference between the coherent signals received by both antennas is essentially related to the geometric path length or range difference to the image point, which depends on the topography. Therefore, the knowledge of the range and the phase difference can be converted into an altitude for each image point. SWOT implements two Synthetic Aperture Radar (SAR) antennas (illustrated in the figure below), each one providing two separate beams at Ka-band (35.7 GHz). As a result, the total swath coverage provided by the interferometer is 120 km, at an unprecedented resolution of 1 km for the ocean (after on-board processing), and 50 m for land water.

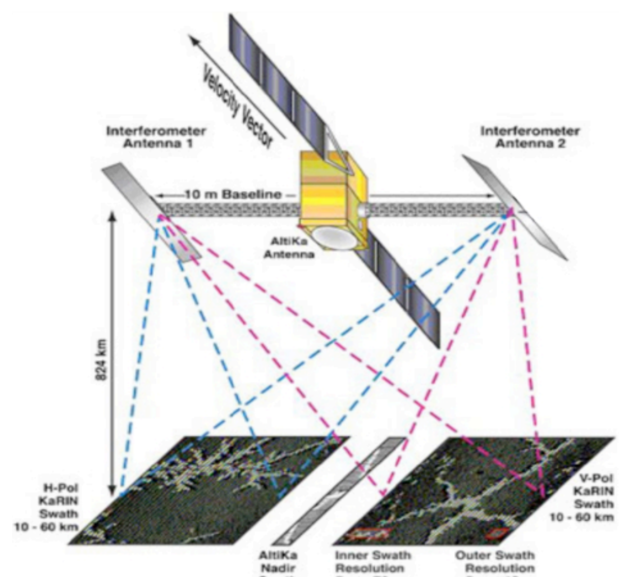

Figure 1. *A conceptual picture of the Ka-band radar interferometer.*

III. TECHNOLOGY DEVELOPMENTS FOR SWOT

We are currently funded by the NASA Earth Science Technology Office (ESTO) Instrument Incubator Program (IIP) to reduce the risk of the main technological drivers of SWOT, by addressing the following technologies: the Ka-band radar interferometric antenna design, the on-board interferometric SAR processor, and the internally calibrated high-frequency radiometer. The goal is to significantly enhance the readiness level of the new technologies required for SWOT, while laying the foundations for the next-generation missions to map water elevation for studying Earth. The first two technologies address the challenges of the Ka-band SAR interferometry, while the high-frequency radiometer addresses the requirement for small-scale wet tropospheric corrections for coastal zone applications.

The key challenges of the interferometer's antenna for SWOT are: 1) support dual channel (scanning) capability per antenna (two beams at two polarizations, one for each swath); 2) stow the large antenna structure inside the launcher fairing; 3) reduced mass of both antenna and boom (while ensuring stiffness); 4) minimize transmission line loss from antenna to radar electronics; 5) beam pointing stability (deployment repeatability and on-orbit thermal stability); 6) on-orbit phase, roll and baseline stability between the two sides of the interferometer's antennas; and 7) meet RF electrical requirements in on-orbit thermal and vibration environment.

To address the above challenges, the interferometer's antenna employs printed reflectarray technology, consisting of a flat reflectarray aperture of 5 x 0.3 m with many printed Ka-band patch elements [3]. The antenna uses free space transmission of power from feeds to reflector, thereby eliminating the need for a transmission line. For the reflectarray, a parameter of each patch element is varied, such as its size or stub trim length, to control the reflected phase over a 360° cycle. The elements are varied across the reflectarray surface to create a collimated beam in the aperture Two slotted-waveguide feed arrays (one V-pol and the other H-pol) illuminate each aperture to provide two independent beams. This antenna technology offers dual beam and dual polarization capability, enabling the flat panels fold compactly for stowage, while the reflectarray panels can provide low mass density, and free-space transmission minimizes loss, as it does not require a deployable waveguide.

A half-scale prototype of the antenna has been completed (see Figure 2). Initial RF performance measurements are presented in Figure 3. These preliminary measurements are in good agreement with the predicted patterns, and further measurements are currently being performed to characterize the effect of distortions of the antenna on critical performance parameters.

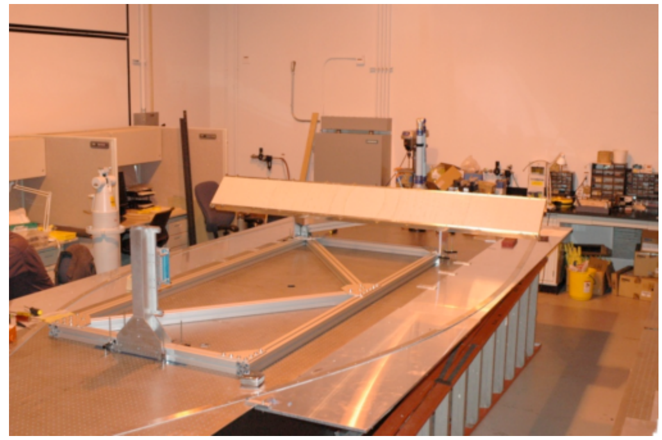

Figure 2. *Ka-band reflectarray antenna prototype assembled on an optical bench.*

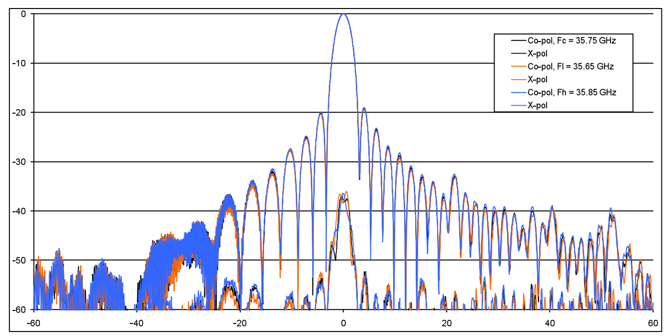

Figure 3. *Co-pol and cross-pol measurements of the prototype antenna at three different frequencies spanning the required bandwidth (35.65 GHz, 35.75 GHz, and 35.85 GHz). Below -30 degrees, where the relative gain falls below -35 dB, sidelobe ripples appear due to feed spillover.*

The resulting radar's output data rate is beyond affordable downlink capabilities for global data downlink. Instead, the raw data over land will be downlinked, while the on-board processor with interferometric SAR processing and multi-looking capabilities will decrease the data rate to reasonable limits for data over the ocean before download.

A prototype of the on-board processor has been developed, and is presented in Figure 4. The processor's performance across the swath is presented in Figure 5. The processor implements Doppler-sharpened, multi-squint SAR processing, primarily to reduce the computational requirements while meeting the low phase error requirements. This approach is similar to beam forming, where a number of beams are created within the real aperture azimuth antenna pattern. For this application, each beam uses 9 pulses, for an azimuth resolution of ~250 m, and an interferogram is formed separately for each beam since they are uncorrelated (averaging can only occur at the interferogram level, during ground processing). On-board averaging of each interferogram down to 1 x 1 km is also performed.

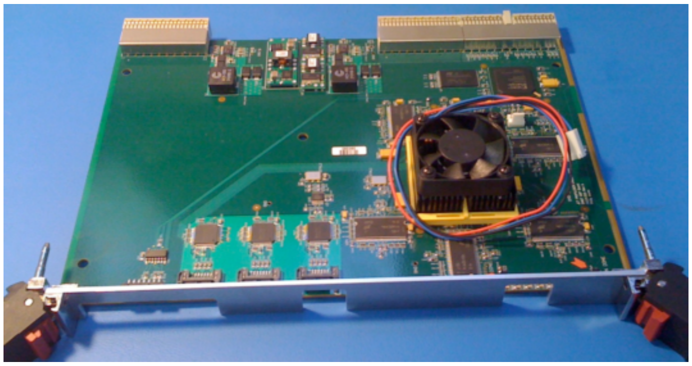

Figure 4. *Prototype of the interferometric on-board processor.*

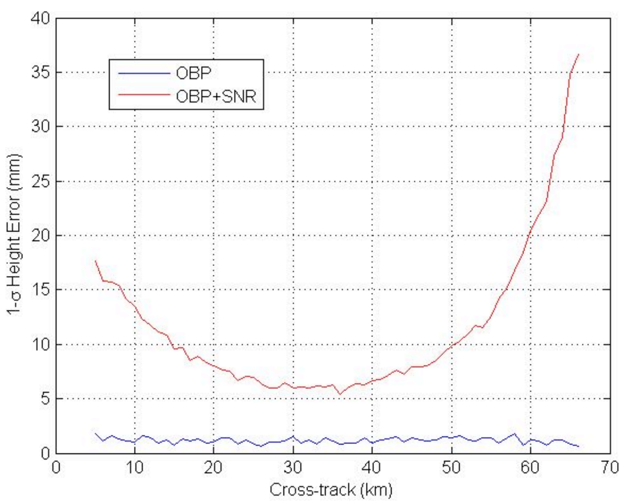

Figure 5. *Performance of the on-board processor across the swath, both accounting for the overall system signal-to-noise ratio (SNR) (red line), as well as without (blue line). The error introduced by the on-board processor alone is less that 1 mm for each 1x1 km^2 output pixel.*

The microwave radiometers carried by previous and on-going altimetry missions do not have the spatial resolution required to resolve the small-scale water vapor features near coastal regions. In order to provide high-resolution coastal altimetry, radiometer channels operating at frequencies of 90 GHz or greater can be added. However, operation at high frequencies without external calibration (that is, without periodic views of hot and/or cold loads) has, to our knowledge, never been flown in space before.

Three high-frequency radiometric channels without external calibration have been developed over the course of this technology development (see Figure 6). This radiometer test bed enables the characterization of the stability of internal calibration for radiometers operating between 90-180 GHz, by characterizing the gain stability of LNAs and the stability of other microwave components at ambient temperature as well as over a range of temperatures. Initial measurements at 92 GHz show that internal references vary smoothly with temperature and are repeatable. Performance measurements at 130 and 166 GHz are on-going.

Figure 6. *Internally-calibrated high-frequency radiometer testbed.*

IV. CONCLUSIONS

In this paper, the status of three key technology developments for the SWOT mission that have been developed under the ESTO Instrument Incubator Program (IIP) have been presented: the Ka-band reflectarray antenna, the interferometric on-board processor, and the internally-calibrated high-frequency radiometer channels.

V. ACKNOWLEDGMENTS

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