Large / Complex Antenna Performance Validation for Spaceborne Radar / Radiometeric Instruments

Paolo Focardi, Jefferson Harrell, Joseph Vacchione
Spacecraft Antennas Group – Flight Communications Systems Section
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, CA, USA
Paolo.Focardi@jpl.nasa.gov, Jefferson.Harrell@jpl.nasa.gov, Joseph.Vacchione@jpl.nasa.gov

***Abstract*—Over the past decade, Earth observing missions which employ spaceborne combined radar & radiometric instruments have been developed and implemented. These instruments include the use of large and complex deployable antennas whose radiation characteristics need to be accurately determined over 4π steradians. Given the size and complexity of these antennas, the performance of the flight units cannot be readily measured. In addition, the radiation performance is impacted by the presence of the instrument's service platform which cannot easily be included in any measurement campaign. In order to meet the system performance knowledge requirements, a two pronged approach has been employed. The first is to use modeling tools to characterize the system and the second is to build a scale model of the system and use RF measurements to validate the results of the modeling tools. This paper demonstrates the resulting level of agreement between scale model and numerical modeling for two recent missions: (1) the earlier Aquarius instrument currently in Earth orbit and (2) the upcoming Soil Moisture Active Passive (SMAP) mission. The results from two modeling approaches, Ansoft's High Frequency Structure Simulator (HFSS) and TICRA's General RF Applications Software Package (GRASP), were compared with measurements of ~1/10th scale models of the Aquarius and SMAP systems. Generally good agreement was found between the three methods but each approach had its shortcomings as will be detailed in this paper.**

I. Introduction

The Aquarius instrument's mission is to measure a map of the Earth's oceans salinity and the SMAP instrument's mission is to map the Earth's soil moisture levels. Both of these instruments make use of a dual radar / radiometer system to remotely make their measurements on a global scale. One of the challenges of these missions is that the data products of interest require knowledge of the instruments antenna radiation pattern in the presence of the service platform over the full 4π steradian sphere surrounding the flight system. One of the key parameters of interest is the ratio of power radiated over specified angular regions to the total radiated power. These beam fractions need to be known to within a few tenths of a percent.

II. Aquarius Mission

The Aquarius instrument, launched into Earth orbit on June 10, 2011, includes a 2.5 m offset carbon-composite reflector fed at L-band by three feed horns. The three beams formed by the antenna are steered away from the antenna's boresight by a few degrees by shifting the phase center of each feed away from the reflector's focal point. These three steered beams form large swaths which are used to facilitate the global coverage of the Earth's oceans. The reflector was stowed during launch to accommodate launch vehicle volume constrains and was deployed when in orbit. In order to maintain minimal aperture blockage and minimal mass, the boom design could not support the antenna assembly on Earth in a 1-G environment without the use of gravity off-load fixtures. This made accurate measurements of the flight system impractical. In addition, the large service platform is not easily included in any such measurements. In order to determine the required antenna radiation patterns, the antenna system was be modeled numerically to the greatest extent possible and those numerical results were validated and/or supplemented using measurements of a 1/10th scale model of the instrument and service platform. TICRA's GRASP tool was used to perform the numerical modeling. At the time, the computing capabilities limited the GRASP model to including the reflector, feeds, and boom of the instrument. None of the service platform could be included. This placed greater emphasis on the scale model which was built to accurately include all key features of the instrument and service platform.

III. SMAP Mission

The SMAP instrument, planned for launch into Earth orbit in October 2014, includes a 6 m deployable mesh antenna fed at L-band by a single horn. The instrument, atop the service platform, spins at 14.7 RPM in order to maximize the swath coverage over the Earth. As was the case with the Aquarius instrument, the size and complex deployable configuration of the SMAP antenna precludes any measurements of the antenna's radiation characteristics. Once again, numerical modeling is used to determine the antenna performance and scale model measurements were used to validate the numerical results. Two numerical approaches were implemented on new more powerful computers. A GRASP model, which now included all elements of the antenna and service platform, was implemented making use of their new Method of Moments add-on (see Figure 1a). Ansoft's HFSS was also employed to model the instrument / service platform making use of their new Hybrid Finite Element-Boundary Integral approach (FE-BI). In addition, the Aquarius numerical model was updated with more spacecraft detail in GRASP (see Figure 1b) to provide more confidence in the modeling approach by comparing results of the newly enhanced model with the Aquarius scale model measurements. The SMAP scale model was built at a near 1/10th scale factor.

IV. Scale Model Measurements

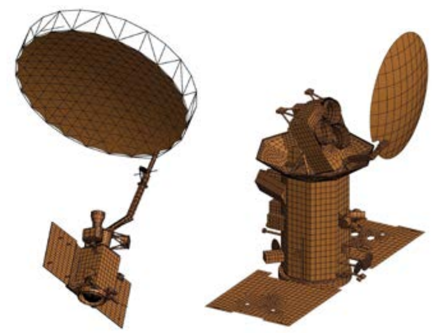
The two instrument scale models were fabricated to a fairly high degree of accuracy. In particular, the representations of the reflectors, feeds, and items very close to the antennas were represented to within a few tenths of a millimeter. For the SMAP Northrop Grumman Astromesh™ perimeter truss-style deployable mesh reflector, known artifacts, periodic surface facets, were included in the machined aluminum surface representation of the scale model. The spinning nature of the SMAP system was also captured by making static measurements of the flight system with the service platform rotated at 22.5 deg intervals.

A cylindrical near-field approach was chosen for both measurement campaigns given its ability to measure much of the radiation pattern while minimizing the level of articulation of the model in the 1-G environment. The JPL cylindrical near-field antenna range also had a large validated legacy of performing accurate measurements at Ku-band (the scaled L-band operating frequency). A downside of the cylindrical near-field measurement approach was its inability to capture radiation from the end caps of the cylindrical scan region. For the Aquarius program, this shortcoming was overlooked since modeling suggested that much of the end cap region had little radiated energy. For the SMAP program, the scale model was measured with its boresight tilted +/- 27deg from horizontal. The two measured data sets taken together provided 4π steradian coverage.

Key considerations for achieving the best possible antenna measurements included design of the scale model to minimize sag in its as measured orientation(s) while rotating on the near-field cylindrical stage; precision alignment characterization using laser metrology; use of well characterized cylindrical horn near-field probe with uniform radiation pattern to minimize range scatter and to allow for probe pattern distortion removal from far-field data product; careful characterization and minimization of test artifacts like component leakage, chamber multipath through the liberal use of high quality absorber wherever possible without shadowing the radiated fields, and data collection beam smear. The goal of these measurements was to characterize the radiated patterns to a level of at least 50 dB below the peak directivity level; it is believed that 60-70 dB level resolution was achieved.

V. Results

In general, excellent agreement was achieved between the measured scale model data and the numerical models (Figure 2). It was found that the HFSS model agreed with the GRASP model with the ability to predict beam fractions to about the 1% level. Below this level, the HFSS model appeared to reach a convergence limit; subsequent increases in the models mesh size resulted in variations in beam fraction at the tenths of a percent level. The GRASP model, on the other hand, presented a stable tenth of a percent level result. The FE-BI approach of HFSS enabled a complete representation of the SMAP antenna system including feed and all reflector, feed, spacecraft interactions. In contrast, the GRASP approach required the use of a tabulated pattern representation of the feed. Using the HFSS results led to revisions of the GRASP model in the area of the feed to more accurately model feed region blockages. GRASP also had two numerical artifacts; a total power normalization offset of unknown origin and a frequency dependent resonance phenomena which raised the sidelobe levels of the radiation pattern (the latter artifact did not occur often). These artifacts made the HFSS results a useful cross reference.



(a) SMAP (b) Aquarius

Figure 1. GRASP Models of the Aquarius and SMAP systems

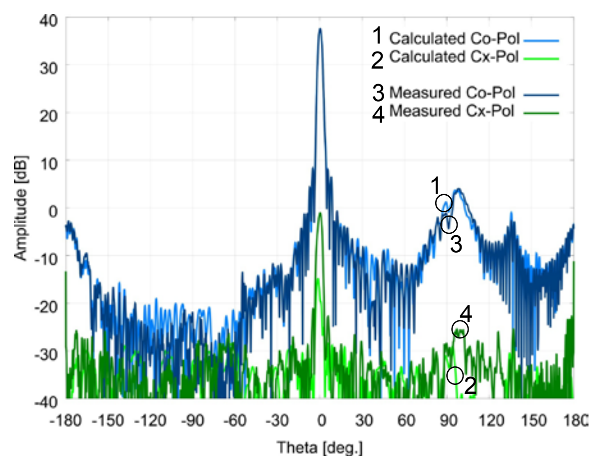


Figure 2. Measured SMAP Scale model data versus GRASP calculations

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