Design of an 8-40 GHz Antenna for the Wideband Instrument for Snow Measurements (WISM)

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***Abstract* — Measurement of land surface snow remains a significant challenge in the remote sensing arena. Developing the tools needed to remotely measure Snow Water Equivalent (SWE) is an important priority. The Wideband Instrument for Snow Measurements (WISM) is being developed to address this need. WISM is an airborne instrument comprised of a dual-frequency (X- and Ku-bands) Synthetic Aperture Radar (SAR) and dual-frequency (K- and Ka-bands) radiometer. A unique feature of this instrument is that all measurement bands share a common antenna aperture consisting of an array feed reflector that covers the entire bandwidth. This paper covers the design and fabrication of the wideband array feed which is based on tightly coupled dipole arrays. Implementation using a relatively new multi-layer microfabrication process results in a small, 6x6 element, dual-linear polarized array with beamformer that operates from 8 to 40 GHz.**

I. INTRODUCTION

The National Research Council releases a survey identifying the highest-priority space-based earth science missions for the next decade. Snow water equivalent (SWE) was identified in the most recent survey as an important parameter to understand the global hydrological cycle [1]. The NASA Snow and Cold Land Processes (SCLP) Earth science mission is a future mission defined to provide the satellite-based capability to perform such measurements. The SCLP concept calls for a combination of synthetic aperture radar (SAR) and radiometry over a broad band of frequencies covering X- to Ka-bands. The authors have been part of a team that has concentrated on maturing technology that would demonstrate the capability needed for this mission [2]. This effort involves the development of a Wideband Instrument for Snow Measurements (WISM), a multi-band instrument that contains both a radar and radiometer operating from X- to Ka-band frequencies. The antenna is a reflector fed with a wideband, dual-polarized feed operating over the entire band. This approach allows for co-boresighting of the beams over frequency allowing for the same scene to be imaged at all bands of interest, an important scientific advantage for this approach.

Wideband phased arrays have been of great interest in recent years [3]. The current sheet antenna (CSA), patented and developed at Harris Corporation [4] is one approach that is capable of achieving nearly a decade of bandwidth. The CSA concept is the basis of the WISM feed design. It allows the feed to cover the required bandwidth while maintaining a relatively constant phase center. Since the design is based on array concepts, it can ultimately be expanded to include active components as required to make an electronically controllable scanning array or meet other beamshaping requirements. This paper describes the design and fabrication of the first-generation WISM feed. This feed has been designed for use in a planned series of airborne experiments with consideration also given to developing the technologies ultimately required for space application.

II. APERTURE DESIGN AND FABRICATION

The aperture design of the WISM feed is a variant of the original coupled dipole array concept developed by Munk [5] also known as the current sheet antenna (CSA). The CSA achieves wideband performance (~9:1) by controlling the mutual coupling between elements in such a way that the active impedance is relatively constant. Previous approaches are based on the optimization of the individual element bandwidth outside of the array environment. When this element is put into an array, its bandwidth is usually reduced by mutual coupling. The introduction of a controlled mutual coupling to increase the bandwidth is one of the main components of the current sheet concept. Harris Corporation has over a decade of experience developing current sheet designs for many different applications covering a broad range of frequencies. In general, the upper frequency range that can be accommodated using standard fabrication techniques is about 18 GHz. An improved fabrication technique was sought in order to expand this frequency range to the required Ka-band upper limit for this application. In addition, it was desired to have the beamformer integrated with the aperture in order to reduce size and weight, an important consideration for all space applications.

An emerging fabrication technology provided the possibility to build the WISM feed at millimeter-wave frequencies. The Nuvotronics PolyStrata® process is a metal/dielectric microfabrication process that is capable of component cost reduction while simultaneously reducing size and weight of existing microwave components [6]. The 3-D substrate architecture leverages a “PCB-like” sequential build and photolithography-based batch processes to achieve high-density integration of thousands of RF components into one monolithic substrate. Rectangular coaxial transmission lines (recta-coax) made of copper allow for extremely low loss component connectivity, high component density, and high signal isolation. The transmission line losses achieved are 2X-10X lower than what is typical with common planar transmission line media such as microstrip, co-planar waveguide or stripline.

III. FEED AND REFLECTOR DESCRIPTION

The reflector antenna feed was developed in a collaborative effort between Harris and Nuvotronics. Harris designed the radiating elements and developed a beamformer weighting scheme suited to the airborne application. Nuvotronics designed the beamformer for the array including all the components, developed the packaging approach, and fabricated the array. The array consists of a 3x3 grid of “modules”, each of which contains a 2x2 group of dual-polarized broadband antenna elements. The progression from module to packaged antenna is shown in Figs. 1 and 2.

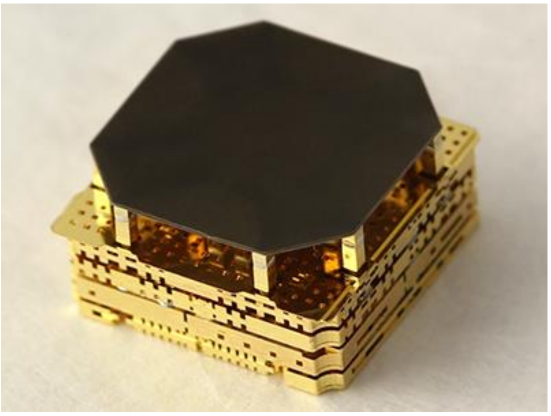

Fig. 1. An antenna module containing a 2x2 group of dual-polarized elements.

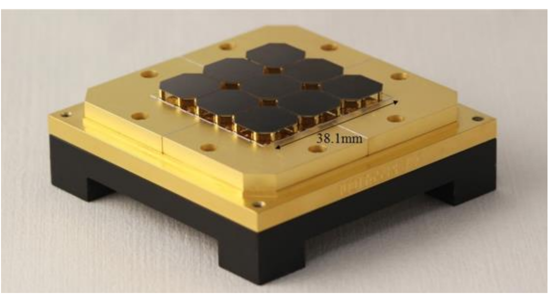

Fig. 2. The WISM antenna feed with the 3x3 grid of antenna modules. The beamformer is contained beneath the aperture which is 38.1mm on a side.

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A large list of components make up the WISM antenna feed beamformer. It is built from 56 individually assembled PolyStrata parts. There are >500 RF part-to-part interconnects in the feed that operate from DC to >40 GHz. There are 36 dual-polarized, 5:1 frequency bandwidth radiating elements and 4 baluns that operate over the same frequency range. There are 82 X-to-Ka-band splitters and 8 Ku-to-Ka-band splitters. Adding up all of the lengths of the transmission lines for the full antenna feed equates to greater than 12m of rectangular coax routed in the 7mm x 38mm x 38mm volume.

The final WISM antenna build was delivered to NASA Glenn Research Center where extensive testing was performed of the feed alone. A detailed description of the measurement approach used to validate the predicted performance is covered in a companion paper to this one. An example of the secondary pattern agreement obtained between measurements and predictions at 36.5 GHz in the azimuth plane of the antenna is shown in Fig. 3. The predictions were made using the Ohio State University Satcom Workbench code. Measured feed patterns were used to obtain the simulated results. Good agreement is obtained between the measurements and predictions.

IV. CONCLUSION

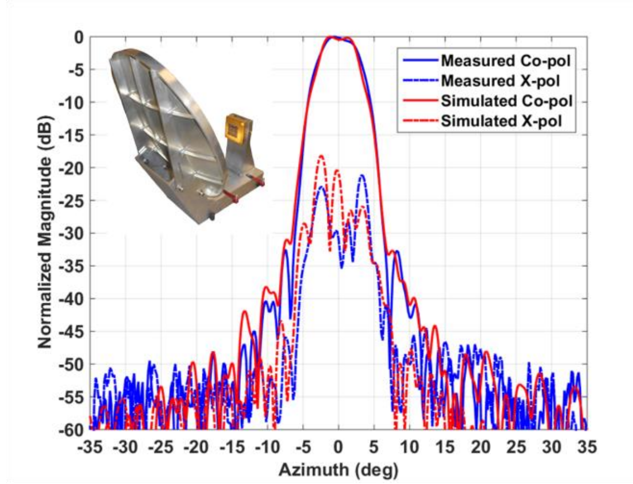

Fig. 3. Comparison of predicted and measured results at 36.5 GHz.

A wideband reflector antenna feed that is capable of millimeter-wave operation has been designed, fabricated and tested. This feed demonstrates the integration capability of the PolyStrata technology and shows a possible approach to integrating co-boresighted multi-band instruments for future satellite-based earth science missions. A demonstration of the WISM instrument is planned in a series of airborne measurement campaigns. Other work is underway to increase the number of radar and radiometer bands for the instrument. The addition of more frequencies all using the same feed will demonstrate the versatility of the wideband feed approach. Other changes will be made to the antenna design to increase efficiency and decrease the feed loss. To the best of the authors’ knowledge, this work represents the most integrated multi-octave millimeter-wave antenna feed fabricated to date.

REFERENCES

[1] National Academy of Sciences National Research Council, "Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future," 2005.

[2] T. Durham, H. P. Marshall, L. Tsang, P. Racette, Q. Bonds, F. Miranda and K. Vanhille, "Wideband Sensor Technologies for Measuring Surface Snow," Earthzine, 02 Dec. 2013. [Online]. Available: http://www.earthzine.org/2013/12/02/wideband-sensor-technologies-for-measuring-surface-snow/.

[3] W. F. Croswell, T. Durham, M. Jones, D. Schaubert, P. Friederich and J. G. Maloney, "Wideband Arrays," in Modern Antenna Handbook, Hoboken, NJ, USA, Wiley & Sons, Inc., 2007.

[4] R. C. Taylor, B. A. Munk and T. E. Durham, "Wideband Phased Array Antenna and Associated Methods". United States of America Patent 6512487B1, 28 January 2003.

[5] B. A. Munk, Finite Antenna Arrays and FSS, Wiley, Chapter 6, 181-213, 2009.

[6] Z. Popovic, D. Filipovic, S. Rondineau, D. Sherrer, C. Nichols, J.-M. Rollin and K. Vanhille, "An enabling new 3D architecture for microwave components and systems," Microwave Journal, pp. 66-86, 2008.