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Performance Evaluation of a Membrane Waveguide Array Antenna

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Abstract— NASA Langley Research Center (LaRC) has pursued the development of tensioned membrane antenna technology for several years. For many applications, it is desirable to have space-based antennas which are very large. As the physical size increases, antennas constructed of conventional materials quickly become too bulky and heavy to be practical for space applications. For some of these applications, such as earth remote sensing, reducing electromagnetic losses in the antenna is also critical. For this reason, there is interest in finding new methods of fabricating large antennas which not only exhibit lighter weight than conventional antennas, but also meet stringent electromagnetic performance criteria.

One configuration which has been investigated by NASA LaRC is a slotted waveguide array antenna constructed of a metallized thin membrane material. Several test articles have been built and tested to validate this configuration. This concept will lend itself to compact packaging for launch, and can be tensioned on an inflatable, rigidizable support structure, which would deploy once on orbit. One major advantage of this planar configuration is that there is no need for fabricating a doubly curved surface (such as for a reflector antenna) from membrane material.

One of the most challenging technical issues to be faced in constructing antennas such as the ones described above is that of designing the antenna and feed network to minimize electromagnetic losses while maintaining compatibility with a light, thin, membrane structure. This paper describes the electromagnetic evaluation of an eight element metallized membrane L-band waveguide array antenna with an integrated membrane feed network. Though there are still some technical hurdles to overcome before this technology is applicable for earth remote sensing from space, the result of the performance evaluation shows that further investigation is warranted.

[2] IEEEAC paper #1148, Updated October 9, 2002

TABLE OF CONTENTS

1. INTRODUCTION

The work described in this paper is part of an ongoing research effort at NASA Langley Research Center (LaRC) to develop large, lightweight antennas for space-based earth remote sensing. NASA LaRC has been involved in developing and evaluating concepts and materials for large, lightweight space antennas for several years [1, 2]. Antennas used for earth remote sensing applications such as soil moisture and ocean salinity must be physically large in order to obtain the necessary resolution at the frequencies of interest. Launching such large antennas into space becomes impractical unless one considers novel materials and lightweight configurations that can be packaged for launch and then deployed once on orbit.

One configuration which has been investigated by NASA LaRC is a slotted waveguide array antenna constructed of a metallized thin membrane material. The concept for this antenna was first developed by Bailey [3] in 1998. A CAD model of the eight element array is pictured in figure 1. Such an antenna lends itself to compact packaging for launch, and can be tensioned on an inflatable, rigidizable support structure which would deploy once on orbit. Another advantage of such an antenna is that the waveguide array is planar and rectangular in shape, which makes constructing a doubly curved surface (such as for conventional reflector antennas) unnecessary.

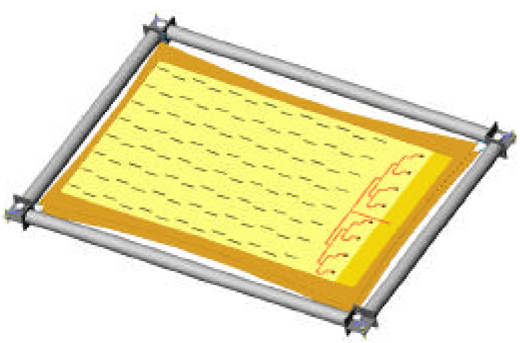

Figure 1 – CAD Model of the Waveguide Array

In addition to weight and packageability, however, the electromagnetic (EM) performance of the antenna must also be considered. For passive earth remote sensing applications, quantities such as soil moisture and ocean salinity are inferred from detecting small differences in thermal emissivities of the scene being viewed. To avoid overwhelming the small desired signal, the total losses of the antenna being used to collect the information must be very small.

In recent years several test articles representing components of this array antenna have been built and tested, and in 2001 an eight element metallized membrane waveguide array antenna with an integral feed network was designed, built, and tested by NASA LaRC, L'Garde, Inc, and GTRI. The performance evaluation of this test article is the subject of this paper.

2. WAVEGUIDE ARRAY TEST ARTICLE

The array is constructed of 0.5 mil Kapton film coated with 3000 angstroms of gold. The waveguide sections comprising the array are nominally sized to conform with standard WR-650 cross section (6.5" x 3.25"). Each section has 13 slots in the broad wall along its length. The antenna array is designed to operate at 1.413 GHz. The computer model for a single waveguide section is shown in figure 2. The overall dimensions of the array are roughly six feet by eight feet.

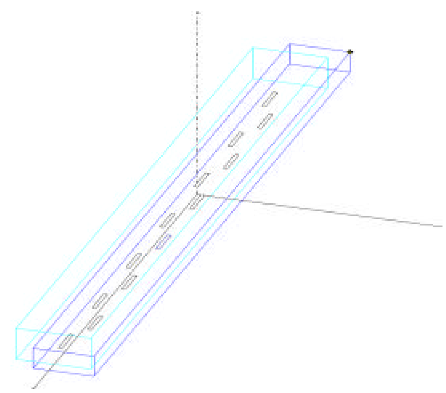

Figure 2 - Computer Model of One Array Element

The feed network of the test article consists of an impedance-matched microstrip power divider network with a single coaxial attachment point. The microstrip line is composed of the same metallized membrane material used in the fabrication of the antenna, and the ground plane is provided by the surface of the array. The spacing for the microstrip line above the ground plane is maintained by low loss, low dielectric Rohacell® foam material. Gaps, or voids, were incorporated into the feed network to allow for folding of the packaged array and network.

3. TEST ARTICLE EVALUATION

Far Field Radiation Pattern Measurements

Initial performance evaluation began in NASA LaRC's Low Frequency Antenna Chamber (figure 3). Principal-plane radiation pattern measurements were accomplished, both co-polarized and cross-polarized, for several frequencies surrounding the design frequency. The co-polarized, 1.413 GHz, H-plane and E-plane patterns are shown in figures 4 and 5. Although the measured patterns validate the ability to fabricate a waveguide array antenna using thin membrane technology, several differences from previously computed patterns deserved further investigation. The asymmetry in the sidelobes is consistent with an undesired source of radiation, for which the feed was suspected very early in the process. The main beam of the H-plane radiation pattern is slightly skewed from boresight indicating other than uniform illumination of the slots along the waveguide sections. Additionally, the cross-polarized patterns exhibited a higher than expected radiation level, supporting the premise that the feed may be a source of undesired radiation. After analyzing the far-field measurement data sets it was felt that planar near field measurement of the test article would provide additional information for evaluation purposes.

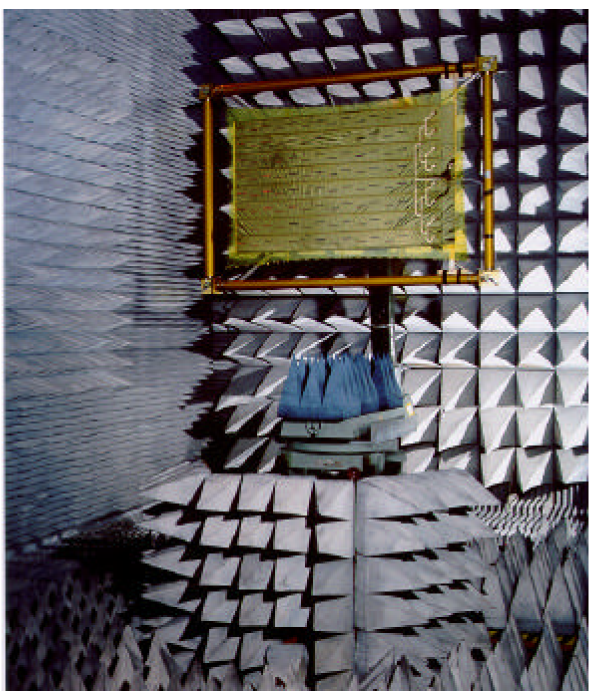

Figure 3 – NASA LaRC's Low Freq. Antenna Chamber

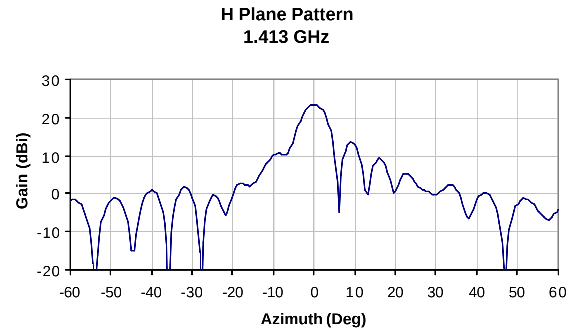

Figure 4 - H Plane Radiation Pattern at 1.413 GHz (LaRC)

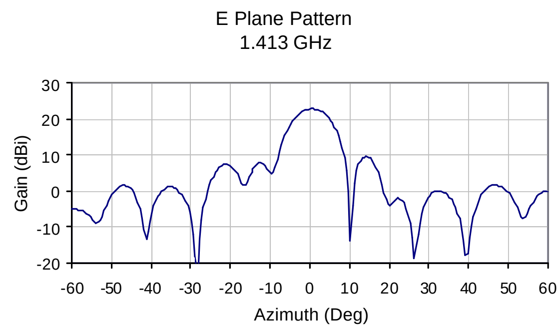

Figure 5 – E Plane Radiation Pattern at 1.413 GHz (LaRC)

Near Field Radiation Pattern Measurements

The membrane waveguide array test article was shipped to the Planar Near-field Measurement Facility of the Georgia Tech Research Institute (GTRI) to continue the investigation. In addition to providing far-field radiation patterns for comparison with previously obtained patterns, diagnostic images of the radiating fields in the measurement plane and in the plane of the array were accomplished.

GTRI's Planar Near-field Measurement Facility is shown in figure 6. The GTRI far-field patterns measurements agreed closely with those obtained at NASA LaRC (figure 7). Figures 8 and 9 present plots of the of the near-field magnitude at 1.413 GHz for both co- and cross-polarizations. In these figures, the feed area of the antenna is located toward the left of the picture. These images support the conclusions that the feed region does appear to be significantly radiating in both co- and cross-polarizations. The range software was unable to truncate an asymmetric window within the data set, and processed far-field data from the separate feed and waveguide portions of the array was not able to be accomplished. The co-polarized near-

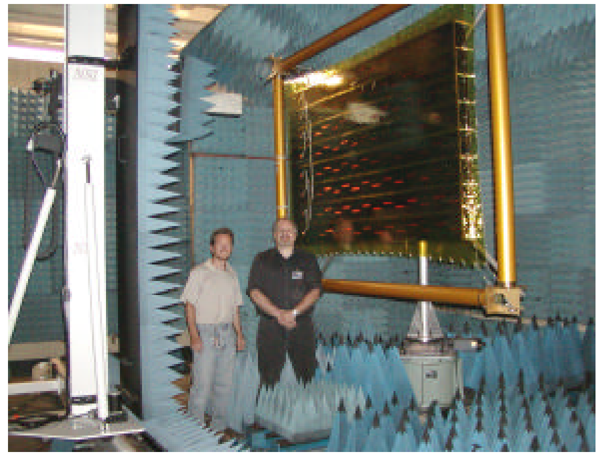

Figure 6 – GTRI Planar Near Field Measurement Facility

field image (figure 8), at 1.413 GHz, illustrates an amplitude taper along the length of the waveguide sections that explains the beam squint seen in the far-field pattern at this frequency. Further analysis of near field data shows nearly uniform excitation along the length of the waveguide sections at 1.426 GHz (figure 10). As expected, the corresponding far-field pattern (figure 11) shows the main beam on boresight. Far field patterns above 1.426 GHz show a beam squint in the opposite direction. This seems to indicate the velocity of propagation is different than expected for the individual waveguide sections. Additional work to investigate this phenomenon is currently underway.

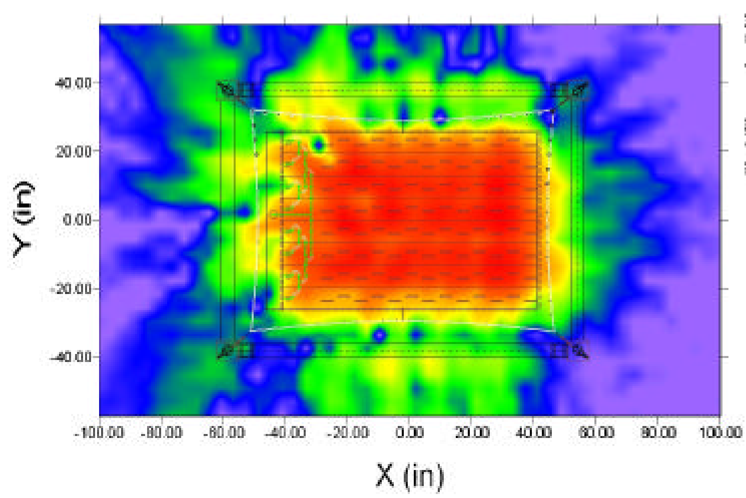

Figure 8 – Planar co-polarized near-field amplitude at 1.413 GHz

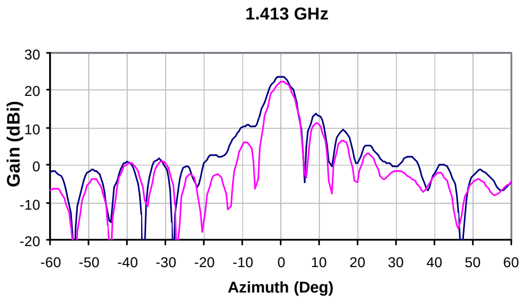

Figure 7 – H Plane Pattern Comparison (LaRC and GTRI)

5. CONCLUSIONS AND FUTURE WORK

The concept of using thin metallized membranes to fabricate a waveguide array antenna was demonstrated. Although the feed network was found to be an undesired source of radiation, this feed design was chosen for its simplicity and compatibility with the membrane construction. The feed technology needs to be improved to be suitable for space-based radiometric applications. Further, the membrane waveguide array appears to be an excellent candidate for communications or other applications where techniques exist to mitigate system losses.

Further investigation into alternate low-loss feed techniques is warranted. To decrease system losses, distribution of receiver functions to the individual elements of the array is an area of interest. Additional work to investigate the velocity of propagation discrepancies within the waveguide sections is underway. NASA LaRC will continue to develop this technology and begin a multi-disciplinary effort to look at on-orbit dynamics and pattern perturbations due to structural deformations of the array.

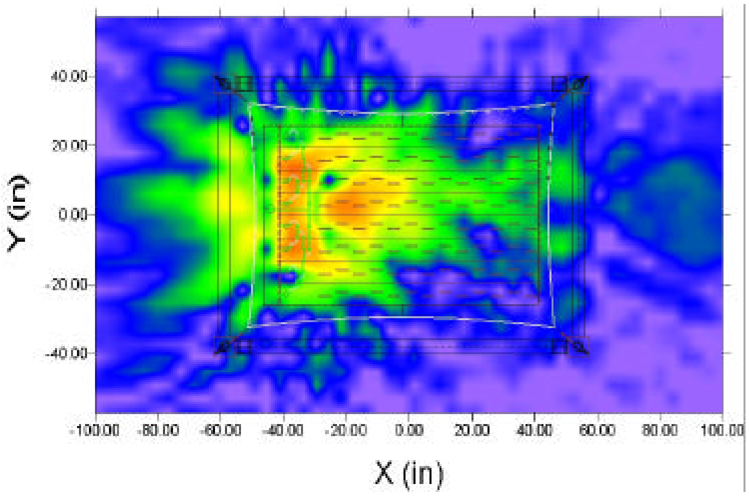

Figure 9 – Planar cross-polaraized near-field amplitude at 1.413 GHz

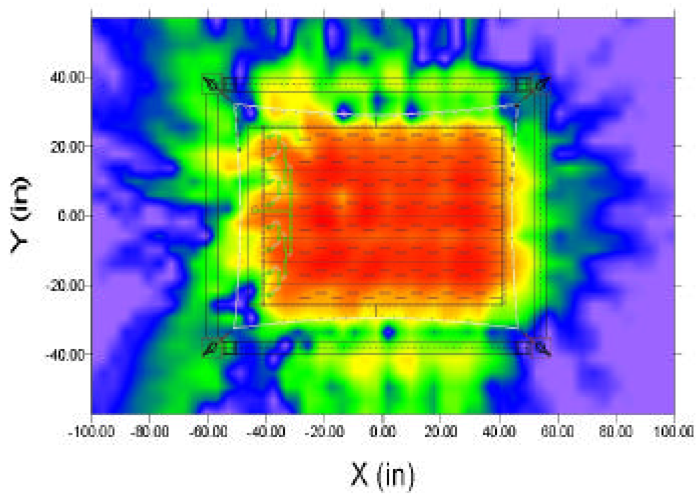

Figure 10 – Planar co-polarized near-field amplitude at 1.426 GHz

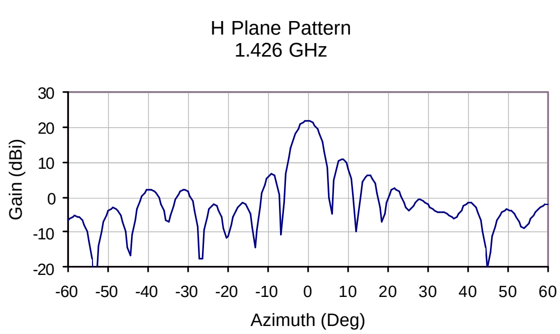

Figure 11 – H Plane Radiation Pattern at 1.426 GHz (GTRI)

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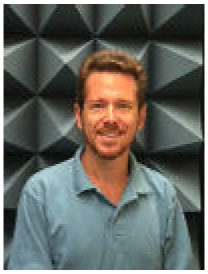
BIOGRAPHIES

Dion Fralick *is a senior research engineer at NASA Langley Research Center where he has been employed for the last three years. For the previous nine years he was employed by Lockheed-Martin providing engineering consultation to NASA LaRC in the area of EM measurements. Mr. Fralick also spent eight years in the United States Air Force. He has authored/co-authored XX publications in various EM measurement areas. Mr. Fralick holds an MSEE and BSEE from Ohio University and a BSET from the University of North Carolina at Charlotte.*

Robin Cravey *has worked at NASA Langley Research Center for 11 years. Her research interests include electromagnetic properties of materials, and she has been the lead engineer in the Electromagnetic Properties Measurements Laboratory since its inception in the early 1990s. She has authored/co-authored 7 publications in the area of electromagnetic properties measurements. Other areas of interest are large, lightweight space antennas and computational electromagnetics. She has a Ph.D. in physics from the Georgia Institute of Technology.*



Glenn Hopkins *is a Senior Research Engineer in the Sensors and Electromagnetic Applications Laboratory of the Georgia Tech Research Institute. In his 15 years with GTRI, Mr. Hopkins has studied and developed a wide range antenna and RF circuit technologies. His primary research interests involve array antennas and unique beam forming and pattern control architectures. He has coauthored seven refereed publications and one U.S. Patent.*

David "Leo" Lichodziejewski *has worked at L'Garde, Inc. for 7 years. He has served as principle investigator and program manager for several NASA contracts including: Solar Sails for advanced space propulsion; the Inflatable Membrane Waveguide Array; and the Power Antenna concept for deep space power generation. Since joining L'Garde in 1995, he has performed design and analysis of space-borne inflatable antennas and solar collectors. He is a member of the Analytic Engineering Section and a senior member of L'Garde's design and program management staff. Mr. Lichodziejewski holds a BS degree BS in Aerospace Engineering from the University of Michigan and an MS in Aerospace Engineering from the University of Southern California. David has authored/co-authored eight papers, and has one patent pending.*

M. C. Bailey *received his BS from Mississippi State University in 1964, his MS from University of Virginia in 1967, and his PhD from Virginia Polytechnic Institute and State University in 1973; all in Electrical Engineering. He retired in 2000 from NASA, Langley Research Center where he was employed for 36 years as a senior research engineer in electromagnetics and antennas. He is currently employed in the same capacity at Research Triangle Institute. While at NASA, he developed and experimentally verified electromagnetic analysis methods and computer codes for a variety of problems. He conceived, designed, developed and tested aircraft flight antennas for a variety of applications, and developed various innovative and unique conceptual designs for large space deployable satellite antenna systems for remote sensing and global communications. He has received 27 awards for recognition of technical accomplishments and has authored or co-authored over 100 technical publications.*

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