SAND2023-04536C

Antenna Fabrication Techniques using Multilayer Insulation Materials for Spaceborne Applications

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Abstract — **Spaceborne assets are subject to the harsh environments of outer space requiring the use of Multilayer Insulation (MLI) to provide the electronics inside the asset with a stable environment to operate. These assets are vulnerable in contested space and require some means of monitoring their surroundings. Most electronic payloads exploit the environmental stability underneath the MLI. These internal components would not be able to monitor the space outside of the asset. Sensing capabilities that can survive the harsh environments must be integrated to the asset's exterior. In this work, a Leaky-Wave Antenna (LWA) radar is designed and fabricated using bonded MLI materials. The fabrication techniques utilized involve both technical embroidery and laser ablation to create the antenna structure out of and directly on the skin of the spaceborne platform itself. This allows the radar to be integrated conformally onto the MLI surface, using materials which have already undergone space qualification. While this effort focusses specifically on a particular implementation of a conformal radar antenna, the processes developed here uncover a much broader and generalized potential of applications including communication, sensing, and imaging use cases.**

I. Introduction

Today as well as tomorrows spaceborne assets impact almost all areas of national and nuclear security. Spaceborne assets can not only collect and disseminate valuable data, well beyond just the visual, but also track terrestrial-based mobile assets in real-time, and active spaceborne platforms potentially pose serious risk to vulnerable earth-based systems and infrastructures. The capability to defend national spaceborne assets from attack/interference is critical for security interests. This effort supports this mission through the cost-effective preeminent detection of approaching threats to our nation's vital resources, to help secure and trust these high-value assets against the threats of tomorrow.

This effort develops novel fabrication techniques for conformal, low-profile, and lightweight leaky-wave antenna (LWA) detection/imaging systems, which fuses technical embroidery (TE) and laser ablation (LA) processes with LWA design. Technical embroidery is an emerging field in additive textile manufacturing where flexible materials and functionalized fabrics are created for a wide variety of uses and purposes, while laser ablation is the process of removing material from a solid surface by irradiating it with a laser beam. Here, thin, conformal antenna designs are designed, modeled, and fabricated using both TE and LA, to create lightweight, flexible, and conformal object detection and imaging radars. This novel development ensures our nation's ability to field advanced lightweight and conformal technologies to protect spaceborne assets.

This effort proposes a unique approach to satellite physical protection systems wherein sensors are integrated into the multilayer insulation (MLI) via the laser ablation process. Specifically, novel fabrication techniques for conformal, low-profile, and lightweight leaky-wave antenna (LWA) detection/imaging systems, are proposed, utilizing Sandia's laser ablation capabilities.

Currently existing radio detection and ranging (RADAR) systems would be fabricated on rigid substrates (e.g., Rogers RT/duroid 5880LZ laminate) and deployed outside of the satellite adding a size, weight power and cost (SWaP-C) burden to the platform. Being able to deploy systems integrated into the platform skin requires no additional space, very little weight and opens the door to a host of new technology implementations. Challenges have included controlling material losses, geometry tolerance accuracies, feed point connections, physical separations from electrical ground (conductive MLI layers) and performance in harsh environments of space.

This efforts success may lead to a host of new technologies being deployed directly on satellite's skin, such as detecting space debris, physical impacts, defects, RF interference location detection, and synthetic aperture applications, among others. This development will ensure our nation's ability to field advanced lightweight and conformal technologies to protect future spaceborne assets.

II. Leaky Wave Antenna Design

A. Initial Geometry Design and Performance

This initial prototype is designed to provide confidence in the ability of the microstrip leaky wave antenna geometry to detect approaching targets, regardless of intent or purpose. This design follows the design provided in [1], however was optimized for performance below 6 GHz. This frequency limitation was implemented to accommodate the ETTUS B210 software defined radio (SDR) which is utilized as a radar source in the operational test bed. The B210 has a maximum operational frequency of 6 GHz, thus leading to the optimization of the antenna geometry to accommodate the frequency limitations of the SDR. This initial prototype design is shown in Fig. 1, with a total overall length of 574.4 mm. The antenna consists of an edge-fed copper microstrip transmission line placed on a 1.6 mm thick woven-glass PTFE Copper-clad substrate (F4BM265). The 4.4 mm width (W_{TL}) of the microstrip transmission line is designed to provide a matched impedance of 50 Ω across the operational frequency band (2.5–6 GHz). Generally, a microstrip would simply transfer energy from the beginning to the end of the transmission line. In this case, a series of ¼ λ impedance transformers (used for matching to 50 Ω) and shorted stubs (for periodic radiation) are incorporated into the geometry.

TABLE I. PARAMETERS OF THE FABRICATED LEAKY WAVE ANTENNA.

Symbol	Leaky Wave Antenna Parameters		
	Parameter	***Dimension***	***Units***
L	Overall Antenna Length	574.4	mm
W_S	Stub Width	7.8	mm
d_L	Distance from Stub	6.8	mm
L_{TX}	Transformer Length	9.6	mm
W_{TX}	Transformer width	2.5	mm
S_L	Stub Length	4.4	mm
D_P	Stub Spacing	52	mm
T	Substrate Thickness	1.6	mm

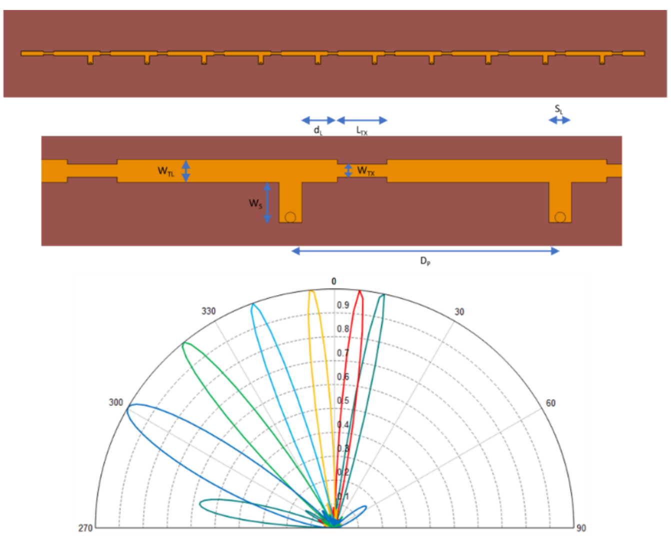

Figure 1. LWA, zoomed-in view indicating important design parameters and elevation patterns at various frequencies of operation within the 2.5–6 GHz band showing its beam scanning as a function of frequency capabilities.

III. LEAKY WAVE ANTENNA FABRICATION

A. Multilayer Insulation Typical Stack Up

The typical stack up consists of an outer cover, reflective layers, spacer layers, and an inner cover. In Fig. 2 is a figure from NASA's document on guidelines for MLI [2]. The outer cover is typically a layer of polyethylene terephthalate (PET) (a.k.a. aluminized Mylar) film that has been metalized using 99.99% pure metal coating on both sides. For an outer cover made of a lower opacity material such as beta cloth (a PTFE-coated fine woven silica fiber) there is a metalized reflector layer (labeled as "Light Block" on the figure) just below the outer cover. The inner cover is generally made of reinforced PET that is metalized on one or both sides.

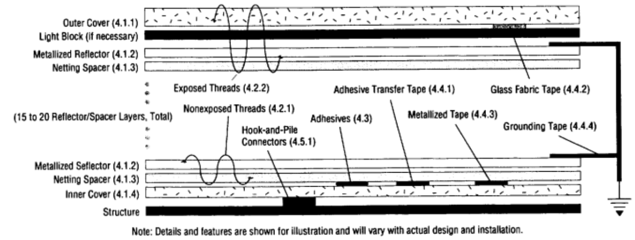

Figure 2. Typical MLI stacking arrangement [2].

B. LWA Fabrications

In Fig. 3 some of the fabricated designs are shown, including both the TE and LA fabrication processes. During the TE process however, the penetrating needle would often either tear the aluminized Mylar material (especially around small features), or the much more rigid PTFE beta cloth material would often break the threads being used in the TE process, resulting in structurally deficient and sub optimally performing antenna. For LA, a major concern was how to properly bond the materials together to provide a suitable stack up. PTFE requires alteration to promote bond-ability. Through resolving the beta cloth bonding issues, LA yielded some very structurally sound, operational antenna. In this presentation, the authors will present the challenges encountered, the techniques used to overcome the difficulties, and the comparisons of the fabricated performance with the predictive models, including backing out the material parameters using numerical optimization techniques. The performance of the fabricated and implemented radar, operating within its test bed environment will also be presented.

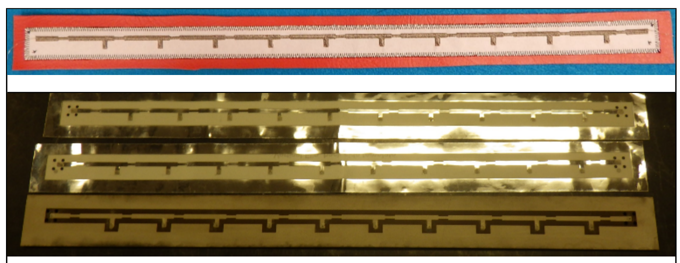

Figure 3. Fabricated LWA using TA (top) and LA (bottom).

ACKNOWLEDGMENT

The authors acknowledge the efforts of James S. Brennan (SNL-CA), Brian D. Rittmann (SNL-CA), Joshua Romano (SNL-NM) and Mathew Garret (SNL-NM) for their fabrication efforts and subject matter expertise

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