Case Study on Deployable Origami Antennas for Terahertz CubeSat Networks

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***Abstract*—The increasing demand for high-speed space communication networks enabled by dense constellations has placed CubeSats as a key enabling technology for future wireless communication networks. An origami antenna for CubeSats operating in the Terahertz Band (0.1-10THz) has been proposed to provide a compact, high-gain wideband solution to meet the demands of ultra-wideband space networks without occupying space within the CubeSat's internal components. The origami horn antenna's initial form is compactly placed on the sides of a 1U CubeSat before deployment in space. One proposed mechanical risk of such origami antenna is potential errors in deployment or degradation of flanges over time. In this paper, the potential errors and degradation are simulated, and the antenna beam pattern, gain, and surface current are shown using the multilevel fast multipole method (MLFMM) computational method in Altair FEKO electromagnetics software.**

***Index Terms*—CubeSat antennas; Origami antennas; Terahertz communication and sensing; CubeSat swarms**

I. Introduction

The utilization of the terahertz (THz) band in CubeSats has gained significant attention in the research community. On one end, CubeSats have been considered a staple of sixth-generation (6G) communications and a key element of the increasingly-popular non-terrestrial networks (NTN) [1]. On the other end, the massive available bandwidth and the very small wavelengths of THz frequencies (0.1-10 THz), potentially enable high-data-rate communications while satisfying the compactness criteria [2]. Due to the high path losses at such frequencies, optimal performance can be achieved through CubeSat swarms, where a large number of CubeSats are utilized in short-distance networks [3].

In such a setup, two conditions must be fulfilled: (i) rapid neighbor discovery and (ii) rapid data exchange. As neighbor discovery does not require a very high data rate, the focus should be on covering more distance; the directivity of the antenna does not play a critical role. During information exchange, a greater directivity is desired to enable a higher signal-to-noise ratio (SNR), which enables faster modulation and coding schemes (MCS) with improved reliability. Thus, we require two different types of antennas, which is cumbersome to achieve given the severe demands of low size, weight, and power (SWaP) on CubeSat implementations.

To concurrently serve the above two purposes, recently, we proposed a deployable Origami horn antenna with two stages. The antenna is connected with a WR4 waveguide (lower frequency cut-off at 137.2 GHz), in which the first stage is a minuscule horn antenna with 4 millimeters in length, encompassed within the body of the CubeSat. The second stage utilizes deployable flanges to create a larger horn. The flanges are fitted on the side of the CubeSat and with this setup, even CubeSats as small as 1U (10x10x10 cm), which are generally utilized for low-data rates applications such as amateur radio and other technology demonstrations [4], can be repurposed to enable high-data-rate communications at THz frequencies.

However, due to the requirements of low-SWaP, mechanical errors in the deployment must be mitigated, as the control mechanism of the flanges can degrade over time. In addition, general wear and tear can cause the mechanism of the flanges not to properly execute. Thus, it is necessary to evaluate the effect that improper deployments can cause on the system performance.

II. Design Methodology

For the origami horn antenna design proposed in [5], this paper focuses on the second stage deployment and analyzes the antenna performance for sub-optimal deployment scenarios. The deployable second stage is designed to unfold and develop into a pyramidal horn antenna as shown in Fig. 1, with the goal of enabling high gain and allowing for high-data-rate communication.

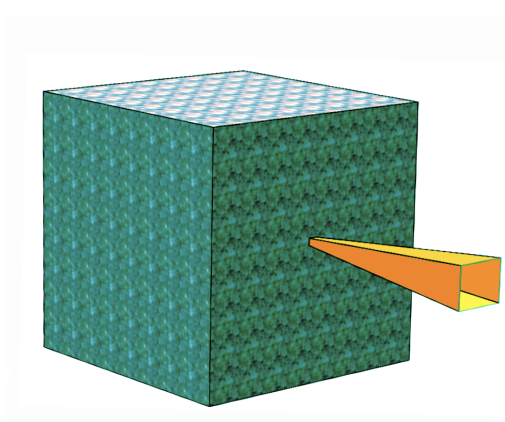

Fig. 1. The pyramidal horn antenna deployed from the side of a 1U CubeSat.

The deployment mechanism can be achieved through various mechanical techniques. The goal is to merge the four sides of the pyramidal horn to create a perfectly joint one. The deployment is shown in Fig. 2 as follows.

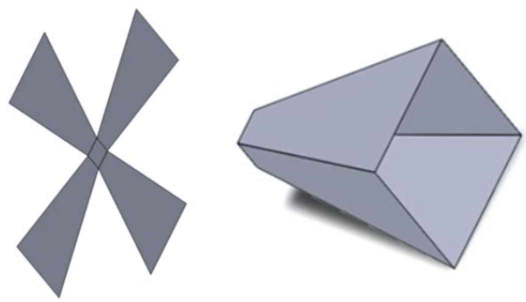

Fig. 2. The antenna deployment mechanism of the pyramidal horn.

For this simulation, a 218 GHz central frequency is chosen for the pyramidal horn. The WR4 waveguide is connected to the pyramidal flare, composed of an 11 mm length, 8.8 mm width, and a flare height of 25 mm. The gain of the pyramidal horn, $G_{pyramidal}$, limited by the horn aperture is given by,

$$G_{pyramidal} = \frac{4\pi k A}{\lambda^2}, \quad (1)$$

where k is the efficiency, A is area of the aperture, and λ is the wavelength [6].

A rectangular waveguide's lower frequency cutoff is given by

$$f_c = \frac{c}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}, \quad (2)$$

where a is width and b is thickness of the waveguide, m and n are the mode propagation numbers and c is speed of light inside the waveguide.

III. Results

The TE10 mode is used to excite the rectangular waveguide feeding the horn antenna. Fig. 3 shows the surface currents along the horn antenna and waveguide as well as shows the 3D gain and beam pattern of the horn. Based on the TE10 mode and type of rectangular waveguide used, the surface current distribution showing the uneven currents is expected and can be an indicator of the losses that may follow misalignment between the top and bottom parts of the horn in comparison to the sides. The surface current diagram can be used as a basis for understanding the deployment risks for the origami antenna. This indicates that for the deployment mechanism to succeed, the placement of the top-right components of the origami antenna is to be deployed first, as errors in side components are more tolerable. The simulations are completed using Altair FEKO software utilizing the multilevel fast multipode method (MLFMM) [7].

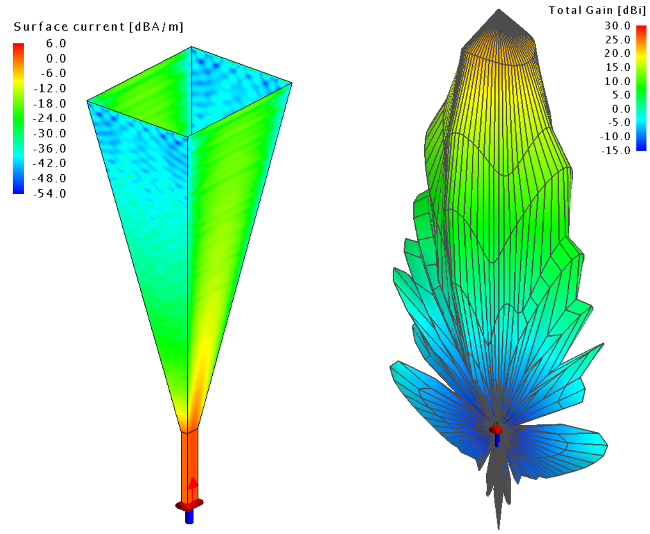

Fig. 3. Surface current and radiation pattern of the pyramidal horn, showing stronger surface current on the top and bottom components of the horn.

IV. Conclusions and Future Work

With the promise of delivering a compact high-gain antenna suitable for a 1U CubeSat, a THz origami antenna is designed. A high-level attempt at understanding the deployment losses is derived from the surface currents of the horn antenna. Our future work will include a more thorough analysis of the different deployment errors that can take place for the antenna, calculating the power losses and beam pattern variations due to degree incremental changes in the components of the origami horn. Additionally, the surface roughness will be studied as part of the evaluation similar to [8].

V. Acknowledgements

We would like to thank Duschia Bodet from the Ultra-broadband Nanonetworking Laboratory for her valuable contribution, and Darius Fadanelli for providing the Altair FEKO license necessary to complete these simulations.

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