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Compact Two-Stage Origami Horn Antenna for Terahertz CubeSat Networks

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***Abstract*—With the rapid proliferation of high-speed satellite communication networks enabled by dense constellations in space, CubeSats are expected to be more compact than ever while maintaining large bandwidth operation. A candidate enabler for high-data-rate CubeSat constellations is the terahertz (THz) band (0.1-10 THz), which supports both compactness and large bandwidth. These two come at the cost of high propagation losses and impose the use of very high gain directional antennas, which on their turn drastically impact otherwise simple tasks such as neighbor discovery and broadcasting with nearby satellites. To simultaneously alleviate the challenges of neighbor discovery while overcoming the high path losses in long links, a THz origami horn antenna utilizing commercially-available WR4 waveguide is presented. The proposed antenna has two stages supporting phases of neighbor discovery and high-data-rate communication. The two stages demonstrate gains of 15.7 dBi and 30.7 dBi, respectively, at 218 GHz. The horn antenna is explored as a solution for enabling CubeSat swarms at terahertz frequencies.**

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

I. INTRODUCTION

CubeSats have been an increasingly popular element of high-data-rate communication in space, capitalizing on reductions in size, weight, and power (SWaP) requirements. Recently, CubeSats have been considered a staple of sixth generation (6G) communication and a key element of the increasingly-popular non-terrestrial networks (NTN) [1]. The utilization of the terahertz (THz) (0.1-10 THz) band in enabling 6G technology is ideal for CubeSats, providing high-data-rate communications at long distances 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 configurations, the challenge is to quickly identify neighbors and establish high-throughput communication, while deploying a compact antenna. In this paper, we propose a deployable horn antenna with a WR4 waveguide, comprising of a two-stage origami structure. The first stage horn is only 4 millimeters in length, while the second stage is 8 centimeters in length, enabling the antenna to be fitted on a compact CubeSat. In these scales, CubeSats as small as 1U, previously utilized for amateur radio and other technology demonstrations [4], can be repurposed to enable high-data-rate communications at THz frequencies.

II. DESIGN METHODOLOGY

With increasing compactness at THz frequencies, the resolution requirements increase fabrication complexity [5]. Thus, linear and planar surfaces such as pyramidal horn antennas are desirable at these frequencies. However, conventional high-gain horn antennas are electrically large and undesirable for CubeSat applications, as the real-estate for the CubeSat is strictly limited to the necessary equipment such as batteries, electronic stacks including actuators and sensors, alongside bulky guidance-equipment such as reaction wheels [6].

Another challenge with conventional horn antennas is that the design parameters and performance, such as the directive gain, are fixed. Thus, a high gain antenna, with a highly directional beam, can prolong neighbour discovery, thereby reducing the effective throughput, especially when CubeSat swarms with significant networking are utilized [7].

Addressing both these limitations, we propose a two stage horn antenna where the first stage is placed inside the CubeSat and occupies a negligible amount of space, with a deployable second stage that unfolds on the external sides of the CubeSat. The initial stage is intended for neighbor discovery and synchronization, while the second stage is incorporated to enable a higher gain, facilitating high-speed communication. The effective aperture of each stage, as well as a qualitative estimate of the ratios of their physical lengths, are presented in Fig. 1.

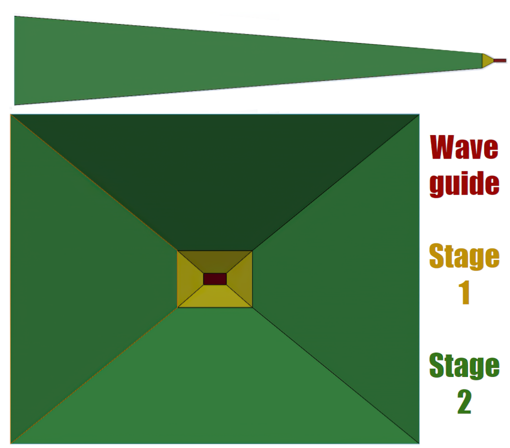

Fig. 1. The two stage design of the antenna showing the scale of each stage in comparison to the waveguide.

A. Horn Antenna Design

A pyramidal horn is chosen due to compactness, ease of manufacture, and low reflection losses; accordingly, it serves as an excellent transmitter as well as a receiver at the frequencies of interest.

However, the gain $G_{pyramidal}$ of the horn is limited by the horn aperture, which 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. To ensure a smooth transition from the waveguide size to the large aperture, the physical length of the pyramid is dependent on the aperture, to avoid abrupt impedance transitions, which would reduce the antenna efficiency [8].

B. Deployment Mechanism

The deployment mechanism in Fig. 2 demonstrates the second stage of the proposed antenna. This second-stage horn occupies one side of the CubeSat. In the event of neighbor discovery, the second stage can simply be un-deployed, and removed back to the side of the CubeSat, allowing the first stage horn to resume the discovery and synchronization phase.

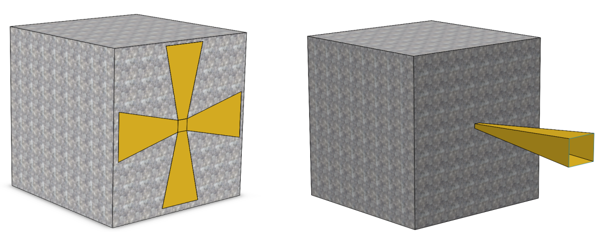

Fig. 2. The antenna deployment mechanism of the second stage, showing the folding of the metal sheets into a horn antenna.

III. Results

The gain and 2D radiation pattern of each stage are presented in Fig. 3. It is seen that the first stage has a smaller gain, providing a significantly larger 3dB beamwidth angle, enabling faster neighbor discovery. The second stage enables a higher gain with a more focused beam that can combat the path loss to allow high speed communication with improved signal to noise ratio (SNR). The gains for each stages are 15.7 dBi and 30.7 dBi respectively at 218 GHz. Figure 4 shows the 3D radiation pattern of each stage. Given the wide-band nature of the travelling-wave horn antenna, it is assumed the reflection coefficient (S11) is significantly low. The simulations are completed using Altair FEKO software utilizing the multilevel fast multipode method (MLFMM) [9].

IV. Conclusions and Future Work

With the promise of delivering higher data rate at compact sizes, THz communication is a candidate solution for high-data-rate CubeSat swarms. A two stage deployable origami antenna is presented to tackle the challenges of compactness as well as neighbour discovery prior to establishing high speed

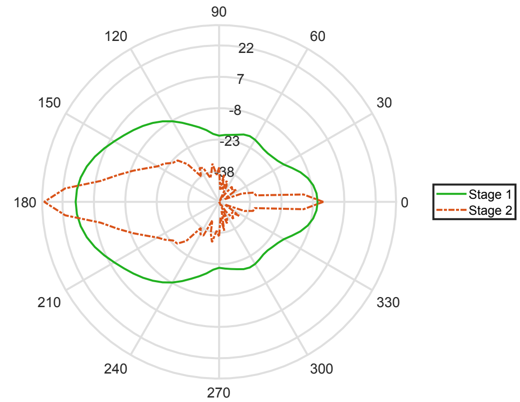

Fig. 3. 2D Radiation pattern showing the gain at each stage.

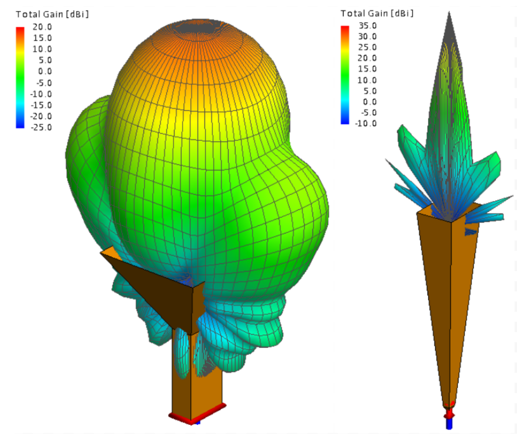

Fig. 4. Radiation pattern for the two stages respectively. The size of the antennas is not drawn to scale.

communications. With a 3dB trade-off in gain, the second-stage antenna can be perfectly equipped on a CubeSat as small as 1U in size.

Our future work will push for more sophisticated origami shapes, including multi-stage petals, as well as integrating the antenna with a full-duplex RF-chain, utilizing a metamaterial circulator to provide isolation between the transmission and reception chains.

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