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Novel CubeSat Combined Antenna Deployment and Beam Steering Method Using Motorized Rods for Terahertz Space Networks

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***Abstract*—A method for compactly deploying and beam steering antennas on CubeSats is proposed and validated. The motorized rods increase the resolution of steering compared to industry-standard single-pivot gimbals, while their deployment mechanism eases the stringent size requirements in space. The very high gain and reconfigurability that can be provided through this design can be utilized to realize space networks in the Terahertz domain, where a low power output and high spreading loss can otherwise cripple the communication distance.**

***Index Terms*—CubeSat antennas; Terahertz communication and sensing; Compact deployment and beam steering**

I. Introduction

CubeSats have become the most exciting technology for space networks and exploration since their emergence, due to reduced cost and complexity in comparison to their counterpart legacy satellites [1]. This has allowed exponentially speeding up the design and operation cycles for space missions as well as an increased incentive for riskier ventures in the space domain [2]. These breakthroughs have paved the way for an era of privatized space networks, such as the SpaceX Starlink constellation [3]. To fully unleash the potential of space networks, higher data rates as well as highly compact devices are required [4]. In this light, the terahertz (THz) band, from 0.1 THz - 10 THz, presents itself as a vast spectral resource that can be exploited for developing wireless technology that can be utilized in next generation CubeSats [5]. THz-band technology is ideal for CubeSats due to the availability of large contiguous bandwidth which can sustain very high data rates, as well as the sub-millimeter wavelengths of THz frequencies, which naturally results in highly compact devices [6]. However, the very high path losses at THz frequencies have remained a key reason for the under-exploitation of this portion of the electromagnetic (EM) spectrum. On the one hand, THz frequencies suffer from absorption losses due to resonance peaks with certain gaseous molecules, mainly water vapor, at specific frequencies [7]. Nonetheless, as discussed in detail in [8]. the absence of atmospheric media in space, and consequently, reduced absorption losses, makes the THz band ideal for inter-satellite communication links. At the same time, with a reduced atmospheric presence within the Lower Earth Orbit (LEO), the absorption losses during up-link and down-link can be mitigated by appropriately choosing the design frequency that avoids these absorption peaks. On the other hand, the very small wavelengths of THz frequencies results in very large spreading losses, requiring high gain, large aperture antennas. Here, the stringent criteria for CubeSat deployments present, among others, a unique challenge of compactness; this limits the options on the antenna configurations which can be utilized for providing high gain. A promising solution in this regard is the utilization of deployable antennas, which have been pioneered and used in recent space missions [9]. Such antennas can provide high gain while meeting the compactness requirement, by being deployed to their full size only after the CubeSats have been launched. However, the current deployment methods in such antennas rely on gimbals and do not allow for dynamic steering with maximum freedom of orientation (360° in one plane). Digital beamsteering with phased antenna arrays can potentially provide such dynamic reconfigurability with high precision. At present however, a lack of mature technology in addition to size limitations reduce their viability. To this end, especially for applications that do not require rapid scanning, mechanical beam steering solutions offer a simpler and more robust alternative.

In this paper, we present a novel method for antenna deployment and beam steering for CubeSat antennas. We first present the design methodology and procedure in Sec. II, following which we describe the results in Sec. III, and we finally conclude our paper in Sec. IV.

II. Design Methodology

Motivated by our previous investigations in [10], the design frequency is selected as 218 GHz. The feed horn is designed optimally, following the design principles outlined in [11]. This feeds into a deployable parabolic reflector, which has reconfigurability enabled through the utilization of four motorized rods, each of which is connected to the parabolic dish through hinges, and provide vertical displacement relative to the satellite edge. Thus, the orientation of the dish, relative to the feed horn located within the CubeSat, result in the mainlobe from this deployable antenna being steered in a desired direction (θ, ϕ), where θ is the elevation angle and ϕ is the azimuth angle relative to the broadside from the CubeSat edge. The relation between the vertical displacements of each rods to the steering direction can be stored in the form of a codebook, and implemented through the motors. An example of the deployment and, by the same principle, the steering mechanism are presented in Fig. 1.

The gain of the parabolic reflector, G, is governed by

$$G = \eta \left(\frac{\pi D}{\lambda} \right)^2 , \quad (1)$$

where D is the diameter, and η is the efficiency. The deployment position of the dish is determined by the focal point equation,

$$f = \frac{D^2}{16d}, \quad (2)$$

where f is the focal length, D is the diameter, and d is depth of the dish. An optimal trade-off between the size and the gain of the dish is considered based on CubeSat size limitations. For maximum efficiency, the focal length is set equal to the diameter. For the deployment mechanism presented in Fig. 1, the direction of the beam is visualized using ray-optics geometry, as shown in Fig. 2.

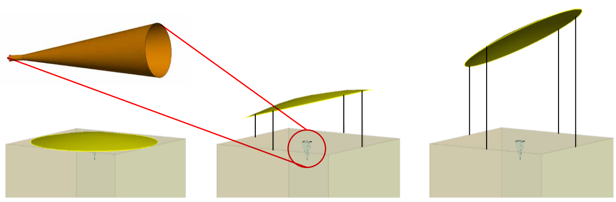

Fig. 1. Mechanical deployment of parabolic reflector away from centered conical horn on the small (20x20 cm) side of the 12U CubeSat. Four motorized rods are shown for robust deployment and steering. The inset shows a zoomed in perspective of the conical antenna.

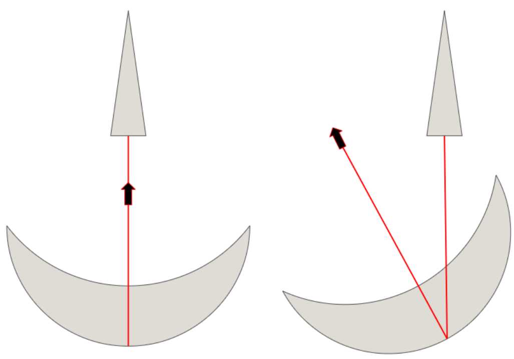

Fig. 2. A 2D visual showing the use of ray optics approximations to calculate the direction of the main antenna beam based on orientation of the dish.

III. Results

The conical feed horn antenna was found to have an efficiency of 68%, with a return loss (S11) of -35 dB at 218 GHz. The consisting dish was designed with a diameter of 19.5 cm, to ensure compatibility with the CubeSat edge. The total antenna gain in the direction of propagation, given by the appropriate configuration of the elevation and azimuth angles θ and ϕ respectively, to the broadside, is shown in Fig. 3. The color bar shows the gain in dB, for the mainlobe. We restrict our analysis to the mainlobe as the sidelobe strengths are much weaker due to the very high directivity; which is an inherent aspect of the design. The steering range in the θ plane is limited by interference with the CubeSat structure as well as an inevitable decrease in the effective electrical aperture of the dish, which reduces the available gain. Nonetheless, high gain and steering capability are enabled with the design.

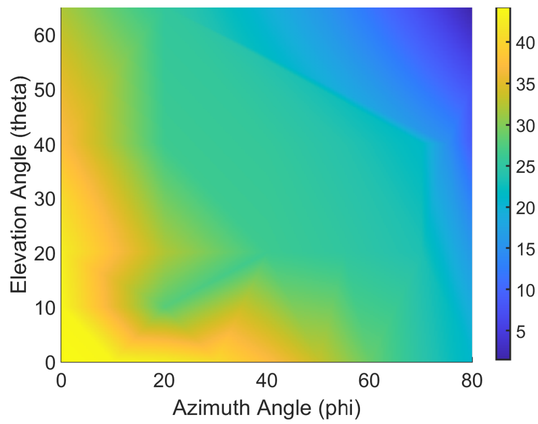

Fig. 3. The gain of the antenna across a wide range of elevation and azimuth orientations.

IV. Conclusion

In this paper, we propose a novel mechanical beamsteering mechanism which can be integrated with deployable antennas. The mechanism leverages individual motors which control mechanical rods that are connected to a parabolic dish. The individual lengths of the rods relative to the CubeSat edge, which govern the orientation of the dish, can be stored as a codebook. We leverage this to demonstrate a very high gain deploybale antenna that can be utilized to realize THz band wireless links in next generation of CubeSats, with more than 40 dB gain provided across a range of elevation and azimuth angle orientation. The realization of the design, and a functional prototype, are a work in progress.

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