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Compact High-Gain Dual-Band Antenna for Full-Duplex Terahertz Communication in CubeSat Mega-Constellations

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***Abstract*—With the rise of CubeSat constellations, higher data rates are desired for commercial and scientific applications in space. A candidate technology for high-data-rate CubeSat communications is the terahertz (THz) band (0.1-10 THz), providing a large bandwidth at smaller wavelengths, pushing towards more compact technology. In this paper, a dual-band feed horn, utilizing a single commercially available WR3 waveguide, enhanced with a deployable reflector is designed and simulated. Gains of 40 dBi and 42 dBi are achieved at 218 GHz and 295 GHz respectively. The antenna can compactly fit on a 12U CubeSat and is explored as a solution for high-gain THz antennas within CubeSat requirements.**

***Index Terms*—CubeSat mega-constellations; Terahertz communication; Compact antennas; Space networks**

I. INTRODUCTION

CubeSats are being launched into space at increasing rates in the form of constellations for both commercial and scientific applications due to significant reductions in cost in comparison to large satellites [1]. One of the desirable CubeSat applications is high-data-rate communications [2]. The terahertz (THz) band, between 0.1-10 THz, is a candidate technology to realize such data rates in space [3]. The THz band has the dual advantages of a vast bandwidth as well as physically compact technology due to sub-millimeter wavelengths. However, one of the key challenges of the THz band is the limited communication distance, due to very high spreading losses. While high-gain antennas can be designed to counter these losses, the criteria become more rigorous in the case of CubeSats, with strict size, weight, and power consumption constraints [4]. In [5], frequencies of 218 GHz for uplink and 295 GHz for downlink (and crosslink) were identified as ideal CubeSat communication bands based on FCC regulations and bandwidth availability. Furthermore, a dual-band performance analysis established a desire for high-gain compact dual-band antennas to suit the given frequencies. In this paper, we propose a compact, deployable, dual-band feed-horn-fed parabolic antenna as a candidate for full-duplex (FD) communication systems to be equipped on CubeSats.

II. ANTENNA DESIGN

The size of an antenna on a CubeSat has been strictly tied to the size of the spacecraft itself. CubeSats are generally defined by 10x10x10 cm cubes classified as "U" units. This classification is visualized by the examples presented in Fig. 1.

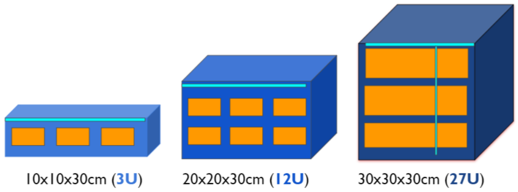

Fig. 1. A comparison of a few different CubeSat configurations.

To compensate for small real estate on CubeSats, deployable reflector antennas have been pioneered and used in multiple recent space missions such as MarCO and RainCube [6]. In this paper, a 12U CubeSat is selected as a realistic option for THz CubeSats to satisfy size, weight, and power requirements. However, this volume does not include deployables and strictly refers to the stringent CubeSat structure.

Thus, we distribute the antenna functionality into two components: 1) a dual-band feed horn optimized for a gain-to-aperture trade-off with FD operation capability and; 2) a deployable reflector that enhances the gain further. The circuitry that feeds into (receives from) the antenna is displayed in Fig. 2, with the commercially-available WR3 waveguide chosen so as to allow both 218 GHz and 295 GHz signals to operate. A compact circulator isolates the TX and RX chains, allowing FD operation through the same horn and waveguide. Such circulators can be designed using non-time-symmetric metasufraces, effectively cancelling self-interference [7].

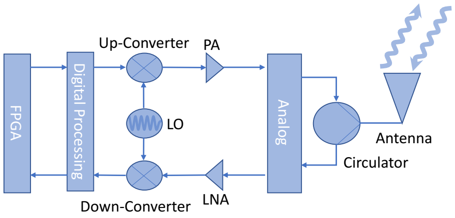

Fig. 2. The working principle of the dual-band antenna.

A pyramidal horn is chosen for the feed 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 [8].

However, the gain $G_{pyramidal}$ of the horn is limited by the horn aperture, which is given by

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

where k is the efficiency, A is area of the aperture, and λ is the wavelength. The gain of the parabolic reflector, $G_{parabolic}$, is governed by

$$G_{parabolic} = \eta \left(\frac{\pi D}{\lambda}\right)^2, \tag{2}$$

where D is the diameter, and η is the efficiency. As shown in Fig. 3, the non-linear relationship between aperture and gain shows that beyond certain limits, significant increases in size barely accrue towards more gain, pushing towards prioritizing compactness. A 96 mm^3 horn aperture alongside a 195 mm diameter dish are chosen for the design with the focal length equal to the diameter for maximum efficiency. The deployment mechanism of the dish is shown in Fig. 4. The reflector is angled at 30 degrees to avoid shadows from the feed as well as reflection from the CubeSat body.

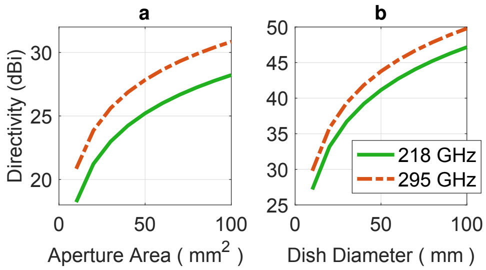

Fig. 3. Gain of a) a pyramidal horn antenna; and b) a parabolic reflector.

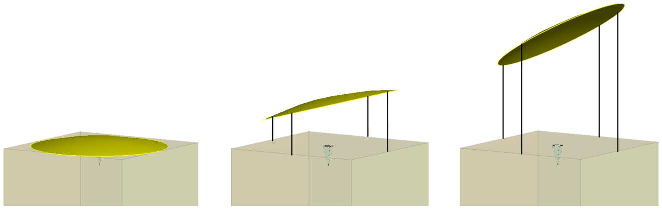

Fig. 4. Mechanical deployment of parabolic reflector away from centered pyramid horn on the small (20x20 cm) side of the 12U CubeSat, allowing solar panels to occupy the larger sides.

III. RESULTS

The S11 parameter of the feed-horn is presented in Fig. 5. It is seen that within the entire bandwidth of interest, reflection losses are consistently below -28 dB, indicating an excellent operation of the feed-horn. The gain of the dual-band feed horn is presented in Fig. 6. It is seen that a gain of more than 40 dBi is possible at an operating frequency of 218 GHz, and due to a larger electrical size, 42 dBi at 295 GHz.

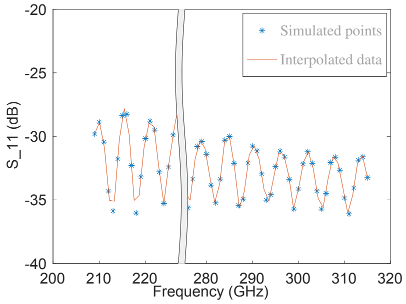

Fig. 5. Reflection coefficient of the feed-horn

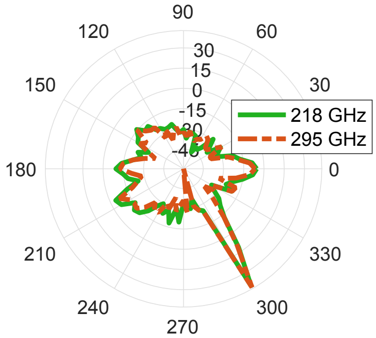

Fig. 6. Polar plot of antenna radiation pattern highlighting gain.

IV. CONCLUSIONS AND FUTURE WORK

With THz-band communications showing promise as a candidate technology for CubeSat mega-constellations, a compact deployable dish antenna fed through a dual-band horn using a commercial waveguide is utilized to enable dual-band FD operation at lower THz frequencies. The simulations in this paper using Altair FEKO software align with results in [5]. The antenna thus fulfills the size requirement and can be utilized to enable THz CubeSat communications.

Our future work will highlight a detailed design process of the metasurface based circulator, and an undertaking towards the prototype for experimental characterization. Additionally, the offset feed of the dish can be optimized to capture more aperture surface area and have higher gain.

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