A Deployable Hexagonal Reflectarray Antenna for Space Applications

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***Abstract*—In this paper, a novel deployable reflectarray aperture for CubeSats is introduced. The proposed aperture achieved an aperture efficiency, η_a, of 78%. When compared to the traditional rectangular aperture, the proposed aperture increases the η_a by 8% while maintaining equivalent packing efficiency. The results of this study were obtained analytically. The proposed aperture can be used to increase the efficiency of space communications systems while providing optimal packing efficiency.**

I. INTRODUCTION

Recent developments in CubeSat satellite technology have enabled easier and relatively inexpensive access to space. One of the major requirements of CubeSats is their small size, which hinders the use of large high gain antennas, such as reflector or Reflectarray Antennas (RA's). Many efforts have been made to design RA apertures that mount on CubeSat buses to achieve maximum stowage efficiency. Specifically, folded reflectarray panels have been proposed to achieve high packing efficiency [1], [2]. However, these designs have rectangular shaped apertures, which limits their aperture efficiency, η_a. It is well known that in order to maximize η_a, RAs aperture should directly correlate with the shape of the feed radiation pattern [3]. Circular shaped RA apertures are typically the best choice, but they cannot be packed efficiently. In this paper, we propose a novel deployable hexagonal RA aperture, which balances the attributes of the traditional rectangular and circular apertures. The η_a of the hexagonal aperture is calculated and compared to traditional RA apertures. Also, a description of the mechanical design is provided.

II. THEORICAL BACKGROUND

A. Aperture Efficiency

The aperture efficiency, η_a, of RAs is the product of the spillover, η_s, and illumination, η_i, efficiencies. Assuming a balanced feed, η_a is a function of the q-factor of the feed antenna radiation pattern and the Euclidean vector of the feed position to each unit-cell. The expressions η_a, η_s and η_i are reported in [3]. Four RA apertures geometries were analyzed in this study, namely, rectangular (30λ×20λ), square (20λ×20λ), circular (diameter = 20λ), and hexagonal (diameter = 20λ). These RAs are designed to operate at 16 GHz and are discretized using 0.5λ×0.5λ square lattice, as shown in Fig. 1. Due to space constraints on the CubeSat bus, the feed is normally fixed, and in this study, it was placed at 20λ on the broadside direction. The optimal η_a for the given conditions of each aperture was calculated numerically and the results are presented in Table 1.

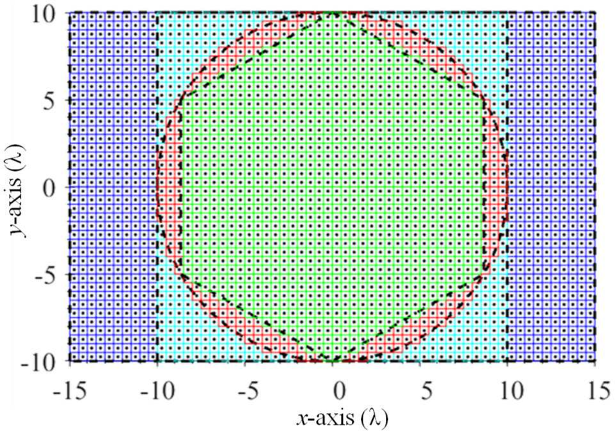

Fig. 1 Four different discretized RA apertures.

TABLE 1 SUMMARY OF THE RA'S PERFORMANCE

Aperture Geometry	A (λ^2)	q	η_s (%)	η_i (%)	η_a (%)	SLL (dB)
Rectangle	600	5.5	87.3	80.9	70.6	-20.8
Square	400	8.0	89.6	84.5	76.1	-22.9
Circle	314	10.5	91.6	85.8	78.7	-30.7
Hexagon	260	12.5	91.0	86.7	78.9	-24.5

Our results show that the rectangular and square RA apertures exhibit the lowest efficiencies of 70.6% and 76.1%, respectively, whereas the circular and hexagonal RA apertures provide the highest efficiencies of 78.7 % and 78.9%, respectively. The higher efficiency of the circular and hexagonal apertures is due to more efficient distribution of the feed's power pattern over their surface. However, the packing efficiency, η_p, of a circular aperture is low; therefore, in practice it is very difficult to provide the necessary surface area that meets the gain requirements of most CubeSat applications. On the contrary, rectangular apertures have high η_p, but they do not provide optimal η_a. A hexagonal aperture can provide an optimal design that provides both high η_p and η_a. However, it should be noted that the hexagonal aperture requires a feed with higher q than the other shapes of apertures in order to achieve its optimal η_a. If such a high q cannot be achieved, a lower q feed antenna could be used, but it should be positioned closer to the aperture.

B. *Radiation Pattern Using Array Theory*

The radiation patterns of the four RA apertures were calculated using array theory, and they are shown in Fig. 2. When compared to the traditional rectangular aperture, the hexagonal RA was able to achieve 4.5dB lower Sidelobe Level (SLL). It should be noted that the rectangular aperture produced the highest gain at 36.7dBi, 3dB higher than the hexagonal, due to its larger area (approximately two times larger than the hexagonal RA). This is explained by the direct proportionality between gain and the aperture's surface area, A, ($G = \frac{4\pi}{\lambda^2}\eta_a A$). Notably, a hexagonal aperture can achieve the same gain with a smaller A, thereby reducing the footprint of the antenna.

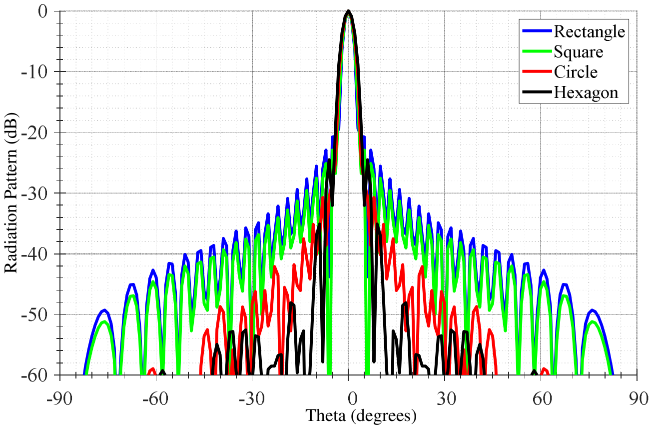

Fig. 2 Radiation pattern of four RAs with different aperture geometries.

III. MECHANICAL DESCRIPTION OF FOLDING PATTERN

The deployable RA is an origami-inspired folding structure based on a flat-foldable hexagonal pattern. When deployed, it forms a larger hexagon with extending points. When stowed, the pattern is a small hexagon with three layers or levels of panels in the pattern. This hexagonal pattern is beneficial because it is flat foldable, meaning that it will lay fully flat in both its stowed and deployed positions. When extending this to structures and mechanisms with thickness, this flat foldability yields parallel panels in each configuration, where the parallel panels may be in different planes. The pattern is a one degree-of-freedom (DOF) mechanism, meaning that it requires only one input to fully actuate. The pattern uses the offset-panel technique to accommodate for thickness [4]. This technique preserves the kinematics of the original paper pattern while accommodating for any desired thickness. While this technique can accommodate any thickness, it does affect the usable area of the pattern. The hinges used in the pattern are membrane hinges [5]. This hinge uses material, such as a film or fabric, to create the hinge. This hinge is easy to implement and manufacture. This also provides a surrogate hinge that efficiently uses space so that most of the area is available for the array.

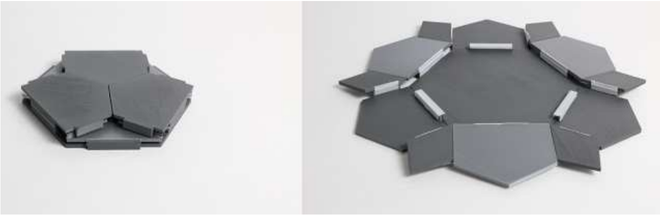

Fig. 3 The hexagonal RA structure at its stowed (left) and deployed (right) states.

IV. CONCLUSIONS

A novel deployable reflectarray aperture design is presented in this paper. The hexagonal shape combines the attributes of circular and rectangular apertures to provide optimal performance in terms of the aperture and packing efficiencies. The proposed aperture achieves the following: (a) at its stowed state, a novel folding pattern provides a smaller footprint on the bus of CubeSats, and (b) at its deployed state, its hexagonal shape provides high gain that meets the requirements of space communications.

ACKNOWLEDGEMENT

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REFERENCES

[1] Hodges, Richard E., et al. "A Deployable High-Gain Antenna Bound for Mars: Developing a New Folded-Panel Reflectarray for the First CubeSat Mission to Mars." IEEE Antennas and Propagation Magazine, vol. 59, no. 2, 2017, pp. 39–49., doi:10.1109/map.2017.2655561.

[2] Hodges, Richard E., et al. "ISARA - Integrated Solar Array and Reflectarray CubeSat Deployable Ka-Band Antenna." 2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, 2015, doi:10.1109/aps.2015.7305460.

[3] Nayeri, Payam, et al. Reflectarray Antennas Theory, Designs and Applications. Wiley, 2018.

[4] Lang, R.J., Tolman, K., Crampton, E. Magleby, S.P., Howell, L.L., "A Review of Thickness-Accommodation Techniques in Origami-Inspired Engineering," Applied Mechanics Reviews, Vol. 70, 010805-1 to 010805-20, DOI: 10.1115/1.4039314, (second-most downloaded AMR papers in 2019), 2018.

[5] Zirbel, S.A., Lang, R.J., Magleby, S.P., Thomson, M.W., Sigel, D.A., Walkemeyer, P.E., Trease, B.P., Howell, L.L., "Accommodating Thickness in Origami-Based Deployable Arrays,[1]" Journal of Mechanical Design, Vol. 135, paper no. 111005, DOI: 10.1115/1.4025372, 2013