Dual-Band Single-Layer Reflectarray Antenna for LEO Satellite Communication

Bagas Satriyotomo
Department of Information and Communication Engineering
Hanbat National University
Daejeon 34158, Rep. of Korea

Seongmin Pyo
Department of Information and Communication Engineering
Hanbat National University
Daejeon 34158, Rep. of Korea
spyo@edu.hanbat.ac.kr

***Abstract*—A reflectarray antenna operates at the frequencies of 12 GHz and 28 GHz for low Earth orbit (LEO) satellite communication is presented in this paper. The dual-band operation achieved by the shared-aperture unit-cell designed on a single-layer substrate. Two different types of elements are employed to provide phase reflection specifically for each operating band. The antenna consists of 15×15 elements at X-band and 30×30 elements at Ka-band. The simulation results show a gain of 24.98 dBi, -16.86 dB sidelobe level (SLL) and 8.1° beamwidth was obtained at 12 GHz. Meanwhile, 32.12 dBi gain was observed at 28 GHz with -23.85 dB SLL and 3.7 ° beamwidth.**

Keywords—dual-band, X-band, Ka-band, single-layer, reflectarray antenna, LEO satellite communications.

I. INTRODUCTION

The demand for high-gain antennas in satellite communication has spurred the advancement of antenna technology aimed at enhancing current communication systems. Reflectarray antennas, in addition to their advantages of ease of manufacturing, flexible design, low cost, and lightweight characteristics, have emerged as a promising solution for long-distance communication, particularly in satellite applications. In a recent study [1], a reflectarray antenna operating in the Ka-band was proposed specifically for LEO satellite communication. Furthermore, investigations have been conducted on wideband Ku-band [2], as well as X-band [3] reflectarray antennas.

The capability to modify the phase reflection of individual elements on a reflectarray antenna offers not only the potential for beamforming but also enables the design of dual-band operation by configuring the phase distribution on its surface. This unique characteristic drives further investigation, such as the development of a dual-band reflectarray antenna based on structure reuse [4]. However, the inclusion of a metal wall within the structure introduces additional complexity to the antenna system. An alternative approach involves the implementation of a multilayer dual-band reflectarray, as investigated in [5-6]. However, this approach results in a bulkier antenna due to the adoption of a multilayer structure. The same bulky structure also arises from the inclusion of a single-layer with an air layer between the substrate and the ground [7-8]. Another avenue of investigation involves a single-layer antenna combined with a combination of elements [9]. Nonetheless, the integration of split ring and phase delay lines introduces complexity to the elements.

In this research, a dual-band shared-aperture reflectarray antenna operating at frequencies of 12 GHz and 28 GHz designed on a single-layer substrate was presented. The unit-cell combines two types of elements that control the phase reflection for each band independently. The proposed antenna has a good gain and aperture efficiency, which make it suitable for LEO satellite communication in X/Ka-band.

II. UNIT-CELL DESIGN AND ANALYSIS

The initial step involves the design and investigation of the element independently for each band. Once the optimum element is obtained, the next step is to investigate the coupling effect caused by the nearby elements. This investigation aims to understand and mitigate any undesired interactions or interference between neighboring elements, allowing for precise control of the phase reflection characteristics of each individual element. The coupling effect is desired to be as small as possible so that the phase reflection for each element can be adjusted independently.

A. X-Band Unit-Cell

A diamond with a length (*A*) of 2 mm was combined with a cross-dipole as the lower band element. The unit-cell was designed on a 0.787 mm-thick Rogers RT/duroid 5880 substrate with a size (*D*) of 12×12 mm^2, which corresponds to approximately 0.48λ at 12 GHz. To generate the reflection phase curve, the length (*P1*) of the cross-dipole was varied while maintaining a fixed width (*W*) of 1 mm. In the second design, four slots spaced (*Lw*) 0.4 mm from the edge of the dipole were applied. Both elements were capable of providing a reflection phase range of 341°. Additionally, as depicted in Fig. 1, the reflection coefficients for the solid cross and slotted elements were above -0.39 dB and -0.37 dB, respectively.

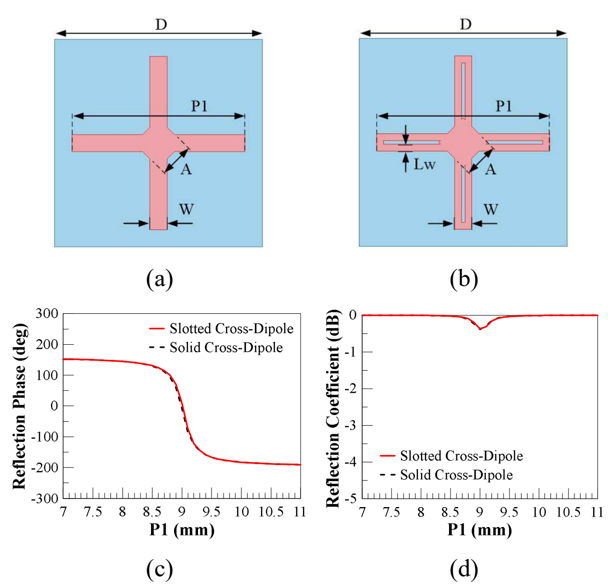


Fig. 1. X-band unit-cell design with (a) solid cross and (b) slotted cross performance comparison in (c) reflection phase and (d) reflection coefficient.

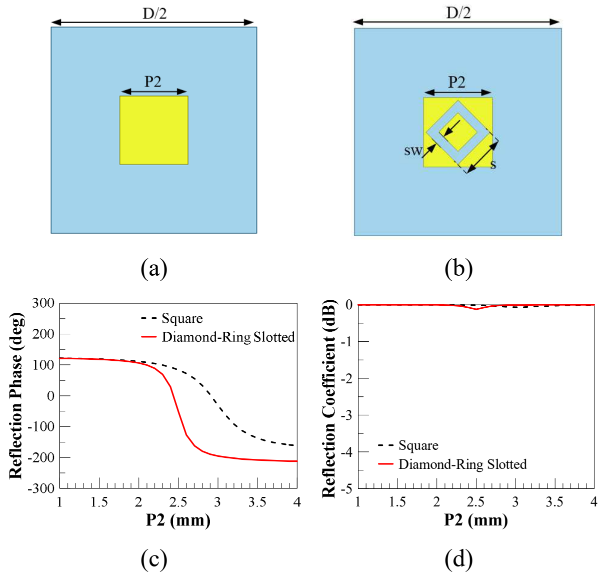


Fig. 2. Ka-band unit-cell design with (a) square and (b) diamond-ring slotted performance comparison in (c) reflection phase and (d) reflection coefficient.

B. Ka-Band Unit-Cell

In the upper band, the unit-cell size was reduced to 6×6 mm^2, which is equivalent to 0.56λ at 28 GHz. A diamond-ring slotted element was selected based on investigation in [10] to enhance the phase reflection range. The slot width (*SW*) was set to 0.2s, while the slot length (s) was calculated by (1), where *P2* represents the patch length.

$$s = \sqrt{\left(\frac{P2}{2}\right)^2 + \left(\frac{P2}{2}\right)^2} \tag{1}$$

As shown in Fig. 2, an improvement in reflection phase range was observed in the unit-cell simulation with a diamond-ring slotted element. The total range of 327° was achieved while still maintaining a low reflection loss of less than 0.13 dB.

C. X/Ka-Band Shared-Aperture

The integration of the elements within a shared-aperture configuration is illustrated in Fig. 3. The effect of Ka-band elements on X-band element performance was investigated in several scenarios. In the symmetrical case, all Ka-band elements have equal sizes, while in the asymmetrical case they differ from each other. From the simulation, it is shown that the reflection phase and reflection coefficient of the X-band are relatively stable regardless of the changing size of the Ka-band elements.

In another scenario, the investigation focuses on the effect of cross-dipole length on the performance of the Ka-band elements at the frequency of 28 GHz. The results in Fig. 4 show that the cross-dipole element has a very small effect on the Ka-band element's performance.

As can be seen in Fig. 5, the current distribution at 12 GHz is mainly concentrated on slotted cross-dipole elements. So, as in 28 GHz, the maximum current distribution occurs on diamond-ring slotted elements. Therefore, both elements have no significant coupling effect on each other. The phase reflection for each element can be adjusted independently without interfering with other nearby elements simply by modifying the value of *P1* for 12 GHz or *P2* for 28 GHz.

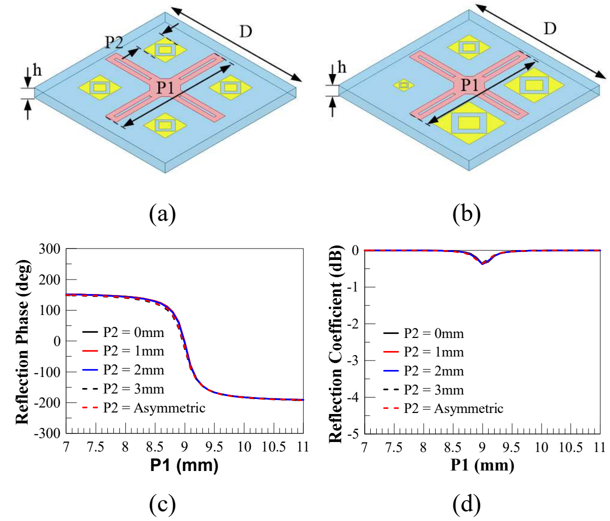


Fig. 3. X/Ka-band shared-aperture unit-cell with (a) symmetrical and (b) asymmetrical *P2* performance investigation at X-band in (c) reflection phase and (d) reflection coefficient.

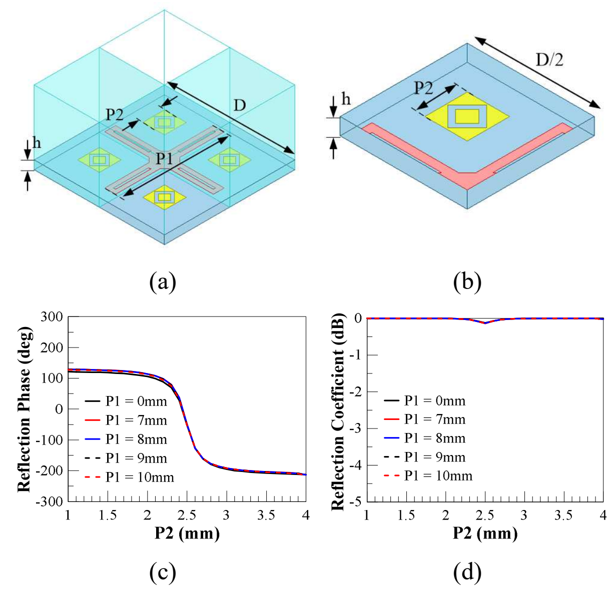


Fig. 4. Unit-cell design illustrated in (a) an X-band unit-cell and (b) a single Ka-band unit-cell. Ka-band performance investigation for the (c) reflection phase and (d) reflection coefficient performance.

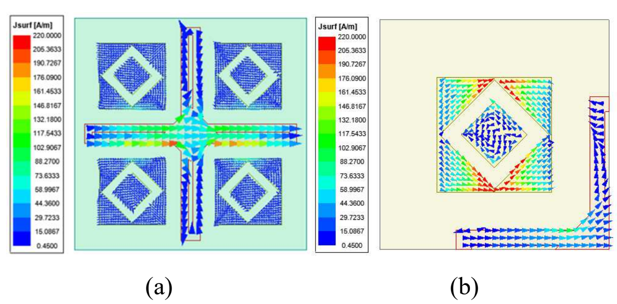


Fig. 5. Surface current distribution at (a) 12 GHz and (b) 28 GHz.

III. Antenna Design

A. Phase Distribution

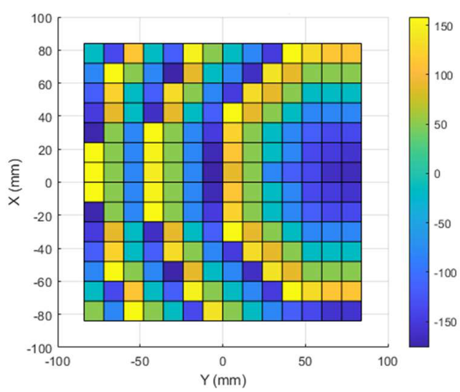
The desired radiation pattern of a reflectarray antenna directed in a certain spherical coordinate (θ_0, φ_0) can be generated by adjusting the phase reflection for each unit-cell on the antenna according to the surface phase distribution, which is calculated based on (2). The ϕ_{RA} represents the phase shift of i^{th} element in (x_i, y_i). Phase constant identified as k_0, while R_i as the distance from the feed to the i^{th} element [11].

$$\phi_{RA}(x_i, y_i) = k_0(R_i - \sin\theta_0\,(x_i \cos\varphi_0 + y_i \sin\varphi_0) \qquad (2)$$

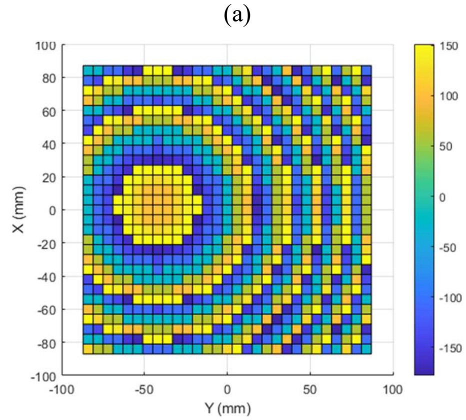
Using the computational method, the phase distribution for the dual X/Ka-band reflectarray antenna was obtained, as illustrated in Fig. 6.

B. Reflectarray Antenna Design

The proposed reflectarray antenna has a total size of 180×180 mm^2 with 225 and 900 elements, respectively, for X and Ka-bands. Designed on a Rogers RT/duroid 5880 with a thickness of 0.787 mm. The reflectarray was illuminated by two pyramidal horn antennas. An offset-focus WR75 standard horn antenna with 40° beamwidth located at (0, 70mm, 126 mm) and a WR34 pyramidal horn with 35° beamwidth located at (0, -45mm, 126 mm) were employed as the antenna feeds. Fig. 7 illustrates the proposed antenna design.



(a)



(b)

Fig. 6. Phase distribution in (a) 12 GHz and (b) 28 GHz.

IV. Result and Analysis

The radiation patterns in the E-pane and H-plane of the proposed reflectarray antenna are shown in Fig. 8. As can be seen from the figures, at 12 GHz, the radiation pattern has a wider beamwidth of 8.1° compared to 28 GHz, with values of 3.7°. This is mainly due to the factors of element number and antenna size from a wavelength perspective. Since 28 GHz has twice as much radiating element as 12 GHz and 16 λ ×16 λ antenna sizes, the generated beam becomes narrower and the directivity increases. On the E-plane, -16.86 dB and -23.85 dB of SLL were observed, respectively, at 12 and 28 GHz, while -18.21 dB and -24.04 dB were on the H-plane.

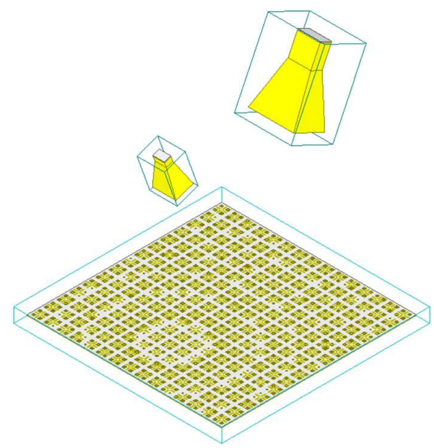
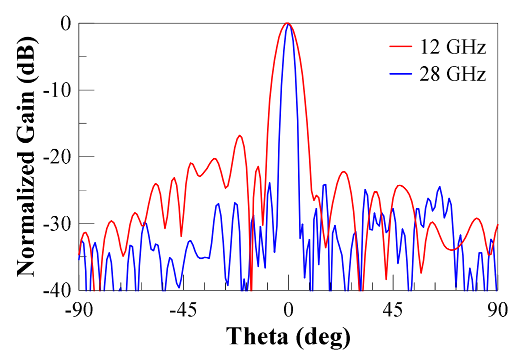
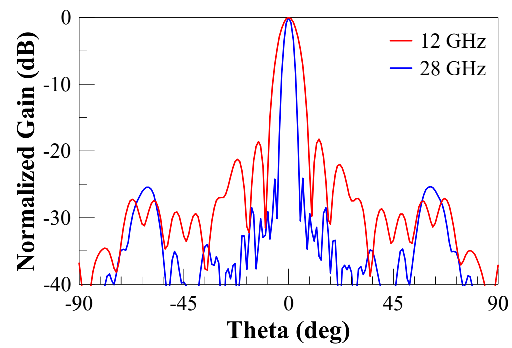


Fig. 7. Proposed reflectarray antenna design.



(a)



(b)

Fig. 8. Normalized radiation pattern in (a) E-plane and (b) H-plane.

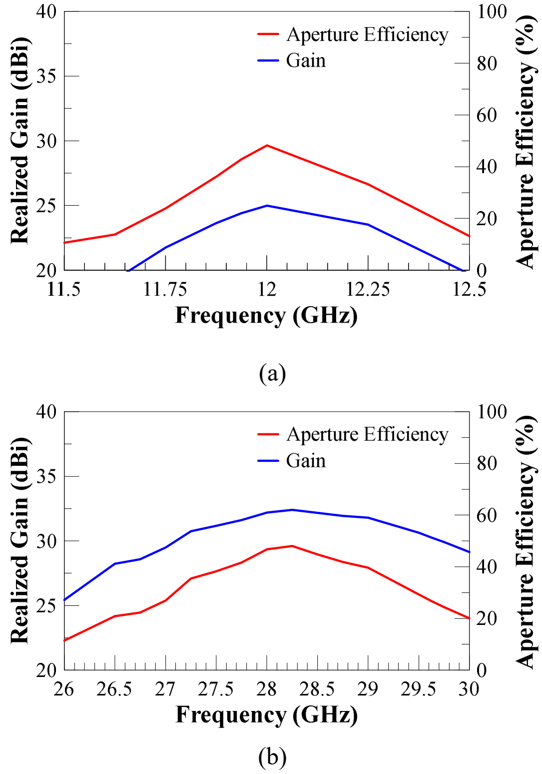


Fig. 9. Gain and Efficiency in (a) 12 GHz and (b) 28 GHz.

In X-band, the highest gain was observed at the center frequency of 12 GHz with a value of 24.98 dBi, as well as the highest aperture efficiency of 48.3%. On the other side, in Ka-band, 32.12 dBi of gain and 46.8% of aperture efficiency were observed at the frequency of 28 GHz. For both bands, the gain and efficiency decrease as the frequency shifts lower or higher. This result shows that the designed antenna has good performance at the proposed frequencies of 12 and 28 GHz.

TABLE I. REFLECTARRAY PERFORMANCE COMPARISON

Parameter	This work	[6]	[7]	[8]
Frequency (GHz)	12/28	7.3/31.75	10/22	8.5/16
Gain (dBi)	24.98/32.12	28.24/40.3	23.6/30.6	22.9/28.8
Aperture Efficiency (%)	48.3/46.8	46/38	41/42	40/44.8
SLL (dB)	-16.86/ -23.85	-17.3/-18.7	-15/-19	-15/-14

Compared to the previous research on dual-band reflectarray designs listed in Table I, the proposed design produces higher efficiency yet has a simpler design with only one layer.

V. CONCLUSION

In this research, a dual X/Ka-band single-layer reflectarray antenna was designed. With a shared aperture unit-cell, the phase reflection of the elements dedicated to each frequency band can be adjusted independently. Slotted cross-dipole elements combined with diamond-ring slotted unit-cell elements were capable of performing reflection phases with a range above 30°. As a result, a gain of 24.98 dBi, an efficiency of 48.3%, and an SLL of -16.86 dB were achieved at 12 GHz. Meanwhile, at 28 GHz, 32.12 dBi of gain, 46.8% of efficiency, and -23.85 dB of SLL were obtained. The proposed reflectarray antenna is a good option for satellite communications.

REFERENCES

[1] S. Anguix, A. Araghi, M. Khalily, and R. Tafazolli, “Reflectarray antenna design for LEO satellite communications in Ka-band,” in *Proc. 15th Eur. Conf. Antennas Propag. (EuCAP)*, Dusseldorf, Germany, 2021, pp. 1–5, doi: 10.23919/EuCAP51087.2021.9411420.

[2] A. J. Joy, S. K. Palaniswamy and S. Bashyam, "Single layer reflectarray antenna for high frequency applications," in *Proc. International Conference on Recent Advances in Electrical, Electronics, Ubiquitous Communication, and Computational Intelligence (RAEEUCCI)*, Chennai, India, 2023, pp. 1-5, doi: 10.1109/RAEEUCCI57140.2023.10134296.

[3] R. Mali and M. K. Meshram, "Design a 1bit high gain 21×21 reconfigurable reflectarray antenna for X-band applications," in *Proc. IEEE Microwaves, Antennas, and Propagation Conference (MAPCON)*, Bangalore, India, 2022, pp. 1398-1402, doi: 10.1109/MAPCON56011.2022.10047125.

[4] Y. Liu, Y. J. Cheng, M. -H. Zhao and Y. Fan, "Dual-band shared-aperture high-efficiency reflectarray antenna based on structure-reuse technique," in *IEEE Antennas Wireless Propag. Lett.*, vol. 20, no. 3, pp. 366-370, March 2021, doi: 10.1109/LAWP.2021.3050204.

[5] M. R. Chaharmir, J. Shaker, and H. Legay, “Dual-band Ka/X reflectarray with broadband loop elements,” in *Microw., Antennas Propag.*, vol. 4, no. 2, pp. 225–231, Feb. 2010, doi: 10.1049/iet-map.2008.0369.

[6] C. Han, C. Rodenbeck, J. Huang and Kai Chang, "A C/Ka dual frequency dual layer circularly polarized reflectarray antenna with microstrip ring elements," in *IEEE Trans. Antennas Propag.*, vol. 52, no. 11, pp. 2871-2876, Nov. 2004, doi: 10.1109/TAP.2004.835144.

[7] X. Li, X. Li and L. Yang, "Single-layer dual-band wide band-ratio reflectarray with orthogonal linear polarization," in *IEEE Access*, vol. 8, pp. 93586-93593, 2020, doi: 10.1109/ACCESS.2020.2986040.

[8] T. Su, X. Yi and B. Wu, "X/Ku dual-band single-layer reflectarray antenna," in *IEEE Antennas Wireless Propag. Lett.*, vol. 18, no. 2, pp. 338-342, Feb. 2019, doi: 10.1109/LAWP.2018.2890766.

[9] X. Mei, P. Gu, X. Tao and D. Ding, "Single-layer dual-band circularly polarized reflectarray antenna," in *Proc. International Applied Computational Electromagnetics Society Symposium (ACES-China)*, Xuzhou, China, 2022, pp. 1-3, doi: 10.1109/ACES-China56081.2022.10065067.

[10] B. Satriyotomo and S. Pyo, "A reflectarray antenna based on diamond-ring slotted elements with enhanced reflection phase," in *Proc. IEEE International Conference on Aerospace Electronics and Remote Sensing Technology (ICARES)*, Yogyakarta, Indonesia, 2022, pp. 1-4, doi: 10.1109/ICARES56907.2022.9993535.

[11] P. Nayeri, F. Yang, and A. Z. Elsherbeni, *Reflectarray Antennas: Theory, Designs, and Applications*. Hoboken, NJ, USA:Wiley, 2018.