FR4-Only Microstrip Reflectarray Antennas for 5.8 GHz Dual-Polarized Wireless Bridges

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Abstract **─** Low-cost antennas are suggested for 5.8 GHz narrow-band, low-power and dual-polarized wireless bridges based on pure microstrip flat reflectarrays. A single layer of the cheapFR4 epoxy is exploited as the substrate for both of the feed and reflector. Detailed design procedure for the feed is reported. Three different elements are used for designing the reflector including rectangular dipole, unbalanced cross and square patch. Using method of moments, performance of the designs is compared from various aspects, including reflector diameter, computational cost, gain, half-power beam-width and polarization purity.

Index Terms **─** Cross-polarization, dual-polarized, ethernet, FR4, microstrip, reflectarray, WiMAX.

I. INTRODUCTION

In spite of their relative ease of fabrication, microstrip reflectarray antennas (MRAs) [1], have not yet replaced parabolic reflectors in commercial systems. This is mainly due to high-cost of low-loss microstrip substrates which makes them expensive even in mass production. At present, wireless bridges are seen to be responsive for many commercial applications and are often narrowband and low-power [2, 3]; e.g., fixed point-to-point (PTP) ethernet and WiMAX links. Specifically, channel bandwidths are in the order of 10 MHz at 5.8 GHz with output power about 30 dBm. Among possible architectures, dual-polarized systems are one of the most attractive. Such systems can be considered as a 2×2 wireless MIMO communication system with polarization diversity and can be exploited in both of LOS and NLOS links [2]. The effective ranges of these bridges can be up to 250 km, using high-gain out-door antennas. Currently, suggestions of producers are limited to parabolic reflectors [2].

Thus far, some attempts have been taken for lowering the cost of MRAs [4-12]. Specifically, the idea of exploiting the FR4 epoxy in the flat reflector is formerly enlightened in [5]. Yet, in all of these works, either the dielectric media of the reflector is double-layer [4, 7, 8-9, 10], or exploits a low-loss dielectric [4, 7, 12] or the feed antenna is not microstrip [4-7, 9-12].

In the present work, low-cost antennas are suggested for narrow-band, low-power and dual-polarized wireless bridges based on pure microstrip flat reflectarrays. A single layer of the cheap FR4 epoxy is exploited as the substrate for both of the feed and reflector. A complete design is suggested for 5.8 GHz PTP applications, including detailed design procedure of the feed. Three different re-radiating elements are used for designing the reflector, i.e., rectangular dipole, unbalanced cross and square patch. Based on full-wave simulation, performance of the designs is compared from various aspects of reflector diameter (*D*), computational cost, gain, half-power beam-width (HPBW) and polarization purity. During the paper, the dielectric constant, loss tangent and height of the FR4 is assumed to be 4.4, 0.02 and 1.6 mm, respectively. The relatively large dielectric thickness is selected to ensure mechanical robustness to make the designs appropriate for out-door applications. Simulation results are carried out using 32-bit FEKO® suit 5.5 software.

II. ANTENNA SYSTEM ARCITECHTURES

The desired specifications of the antenna system are: low-cost, simple-to-realize, high-isolation and low cross-polarization (X-pol). To satisfy the first two properties, both of the feed and reflector are selected to be single-layer microstrip with FR4 substrate. Due to inevitable excitation of surface waves in the microstrip substrate, high port isolation can be reached using two separated single-polarized feeding microstrip antennas (MSAs). High-polarization purity is achieved by proper selection of reflector elements. Three simple-to-realize such structures are dipole, cross and square patch. Since dipoles support only one polarization, their exploitation required two individual single-polarized reflectors. In contrast, cross and square supports both polarization and thus, one dual-polarized reflector suffices. However, the design tolerance of cross is less than the others. For reducing the blockage, offset-feed configuration is selected with θ_i = 30° illumination angle with respect to the reflector normal direction. The said two antenna

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systems are schematically described in Fig. 1, which are in accordance with the solutions suggested in [2].

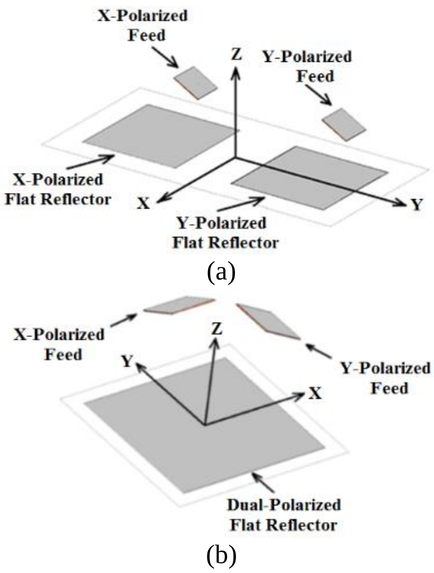

Fig. 1. Responsive antenna system architectures: (a) double-feed single-polarized MSA, and (b) double-feed dual-polarized MSA.

III. MICROSTRIP FEED DESIGN

It is aimed to feed the reflector by single-layered linear-polarized MSAs with FR4 substrate. Since one of the most important design criteria is polarization purity, the feed is designed to provide low X-pol. The normal range of F/D is 0.3 to 1.0 [13], where F designates the focal length of the reflector. Higher values of F/D lead to better X-pol performance at the cost of larger dimensions [13]. Thus, a proper feed should marginally provide $F/D \cong 1$. Following [14], the feed pattern is assumed to be of the form $\cos^n\theta$. As the first feed scheme, a single square patch on a finite square substrate is studied, as depicted in Fig. 2. The side lengths of the patch and the substrate are $L_p \cong \lambda_g/2$ and $L_s = 3\lambda_0/2$, respectively, where λ_0 is free-space wavelength and $\lambda_g = \lambda_0/\sqrt{\varepsilon_r}$. The corresponding radiation pattern is depicted in Fig. 3. This design is improper, due to pattern asymmetry. Nevertheless, E-plane pattern and its related efficiencies are computed and reported in Figs. 4 and 5, respectively [14]. As usual, illumination, spillover and total efficiency are, respectively, designated by η_i, η_s and η. The optimum valued for F/D is 0.4 which is far from unity and leads to poor η.

Next, a 2×2 array of square patches is investigated. This scheme is depicted in Fig. 6, where L_s and L_p are the same as the previous case and the length L is used as the optimization parameter to provide $F/D \cong 1$. Noting to Fig. 7, the optimum value for L is 15 mm, ensuring the most symmetric pattern due to the close values of F/D in E- and H-planes. The length L, also, affects the reflection from the feed, as reported in Fig. 8 for L = 15 and 18 mm, which shows superiority of L = 18 mm. Figure 9 indicates that the difference in η for the said values is negligible, suggesting L = 18 mm. However, since the wire port is used in simulations, it is likely that capacitive behaviour of the real connector compensates the shift in $|S_{11}|$ of the L = 15 mm case. Hence, L and F/D are taken to be 15 mm and 0.9, respectively. The radiation pattern is reported in Fig. 10, which in accordance to Fig. 7, is symmetric and ensures proper illumination of the reflector. Besides, its low X-pol, shown in Fig. 10 (b), ensures sufficient polarization purity for commercial applications. Thus, efficiency curves can be computed based on the average n factor of E- and H-plane patterns, which is found to be 7.69 [4]. The corresponding efficiency curves for the second feed scheme are depicted in Fig. 11.

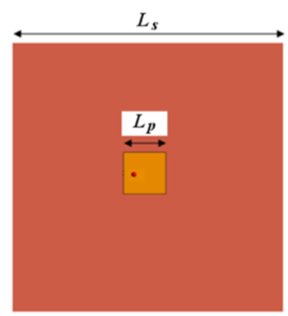

Fig. 2. The first feed with L_s = 78 mm and L_p = 12 mm (red spot: excitation).

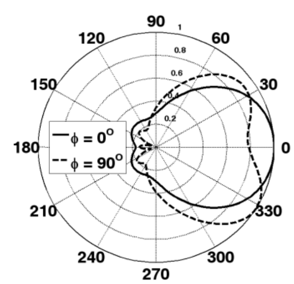

Fig. 3. Radiation patterns of the first feed.

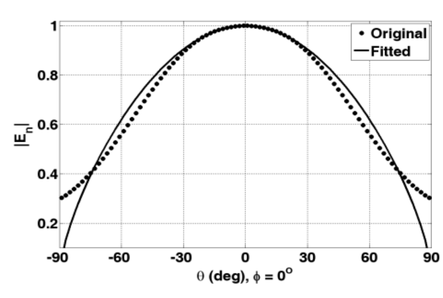

Fig. 4. E-plane pattern of the first feed (n = 0.69).

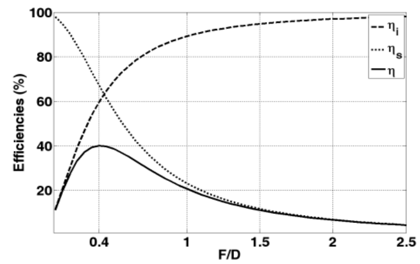

Fig. 5. *E*-plane efficiencies of the first feed.

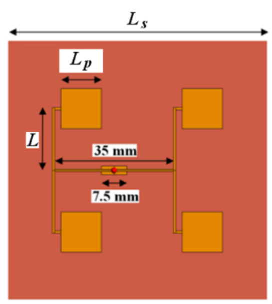

Fig. 6. The second feed (red spot: excitation).

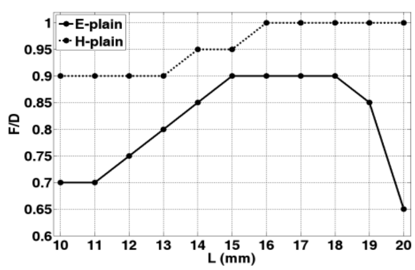

Fig. 7. *F*/*D* vs. *L* for the second feed.

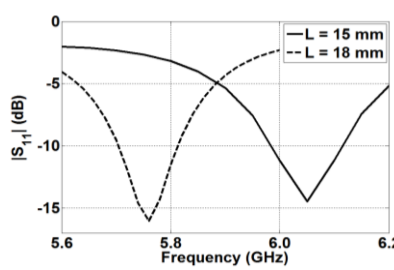

Fig. 8. Simulated $|S_{11}|$ for the second feed.

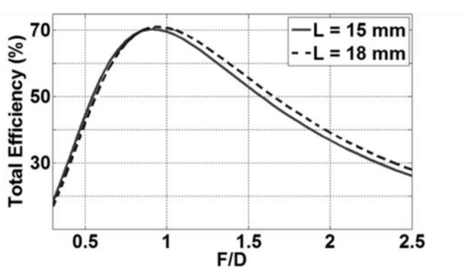

Fig. 9. Total efficiency vs. *F*/*D* for the second feed.

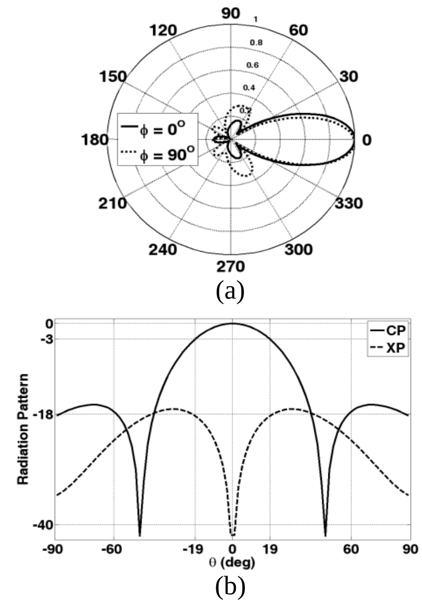

Fig. 10. Radiation pattern of the second feed: (a) Co-pol at orthogonal planes, and (b) Co- and X-pol at *E*-plane.

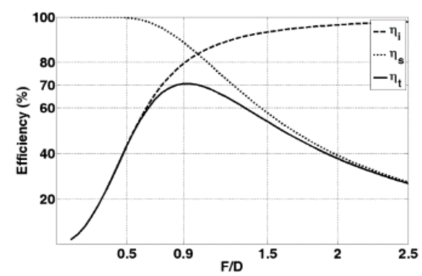

Fig. 11. Efficiencies of the second feed (n_{av} = 7.69).

IV. UNIT CELL DESIGN

To cover both antenna architectures introduced in Section II, three unit cells are investigated for designing the reflector: dipole, cross and square. Geometry of these cells is described in Fig. 12. These are selected due to their low fabrication complexity and low X-pol. The dipole width is taken to be 2.5 mm ≅ $0.05\lambda_0$, ensuring negligible transversal current density distribution. This allows computing the delay characteristic of the cross by considering only one of its arms. Thus, delay response of the cross is assumed to be the same as the dipole. The delay characteristics of the dipole and square are reported in Fig. 13, assuming offset-fed configuration with illumination angle of θ_i = 30°.The dipole supports only one and the rest, supports both polarizations. It can be predicted that the square provides more gain due to its more metallic surface with respect to the others. Due to their narrow width, dipole and cross are expected to exhibit less X-pol compared to the square. However, the design tolerance of cross is less than the others. It should be noted that due to narrow bandwidth of commercial wireless bridges, the narrow bandwidth of these unit cells is tolerable.

Although the infinite array approach is currently the most used method for computing the delay characteristic, here, the finite array approach is exploited wherein, a unit cell is surrounded by eight other cells of the same size with inter-element spacing of P = 0.95λ_g. This method is followed because of its less simulation time. Specifically, due to relatively large dielectric constant of FR4, even using a course mesh, the eigen-mode analysis becomes too slow at 5.8 GHz. Yet, using the said approach, Green's function of the substrate can be exploited which significantly speeds up the analysis.

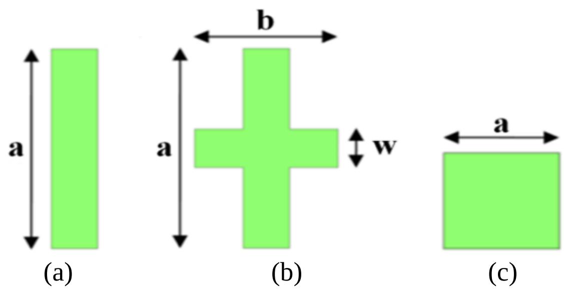

Fig. 12. Geometry of the investigated unit cells: (a) dipole, (b) cross, and (c) square.

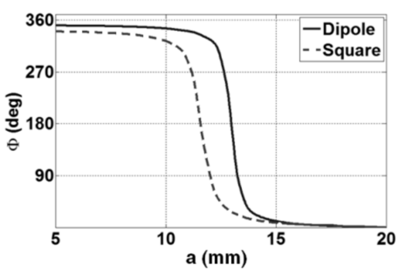

Fig. 13. Delay characteristics of unit cells.

V. MICROSTRIP REFLECTOR DESIGN AND PERFORMANCE COMPARISON

By the introduced unit cells, a variety of reflectors is designed with different number of elements (N) and analyzed using method of moments (MoM). For efficient usage of computational resources and minimizing the simulation time, three tricks are applied. The first is making use of symmetry for the feed antenna and reflectors with dipole and square elements. This cannot be done when cross elements are used due to the imposed asymmetry in the reflector. The second is infinite substrate assumption for reflectors and thus, exploitation of the Green's function. The third is decoupling the analysis of the feed and the reflector.

The reflectors are all square shaped, consisting of a single-layer of FR4, grounded by a metallic PEC plane. The dependence of N on D and the peak memory usage are reported, respectively, in Figs. 14 and 15. As can be seen, the required memory for the analysis of reflectors with square elements increases dramatically with N. This, put limitation on the range of N for full-wave simulation of MSAs with such elements. Noting to Fig. 16, gain of MSAs with dipole and cross elements are essentially the same. As well, it shows that MRA with square elements provides about 3 dB more gain with respect to the others. The HPBWs are reported in Fig. 17, showing that this parameter depends on D and not the element shape. Please note to monotonic increase of gain in Fig. 16 and monotonic decrease of HPBW in Fig. 17 as D increases. These can be regarded as a convergence analysis which validates the design procedure and the exploited simplifying tricks [15]. Comparison of the polarization purity of the designs can be made by Fig. 18, where the average X-pol in the HPBW is reported for MRAs with cross and square elements. This figure demonstrates that cross elements provide about 20 dB less X-pol compared to square elements. Since the said two elements have the same performance in the sense of HPBW, this result justifies using cross elements for secure dual-polarized links. Gain patterns of MRAs with cross and square elements with 22.8 dB gain and, respectively, 49 cm and 35 cm diameter are reported in Fig. 19. The related layout and the 3D pattern for MRA with cross elements are depicted in Figs. 20 and 21. Based on Figs. 16 and 17, the performance of dipole and cross elements is expected to be the same. This can be verified by considering the gain patterns of MRAs with the said elements and D = 49, which is depicted in Fig. 22. Thus, gain pattern of the high-gain low X-pol MRA with D = 115 cm can be predicted from its dipole equivalent, as depicted in Fig. 23.

It should be noted that all the results reported in this section are derived using only one feed antenna with single polarization. This may seem to be in contradiction with the claim of the work. Nevertheless, both of the architectures introduced in Fig. 1 ensure extension of the aforementioned results to the situation wherein both feed antennas illuminate the reflector with two orthogonal polarizations. This can be justified noting that first, in both of the responsive antenna systems the feed antennas are placed on separated substrates and second, the X-pol of the feeds are sufficiently low, as reported in Fig. 10 (b).

At last, the design procedure of the antenna system can be summarized as follows: First, the compromise should be made between X-pol and gain; this determines the shape of unit-cells. Second, the diameter of the reflector is determined based on the desired HPBW from Fig. 17. Third, the design tolerance determines the proper choice of architecture, shown in Fig. 1.

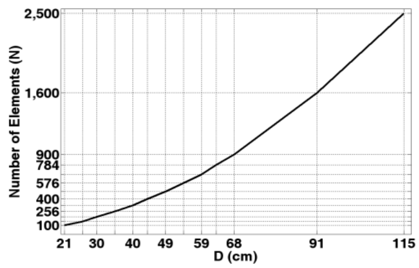

Fig. 14. Number of elements vs. reflector diameter.

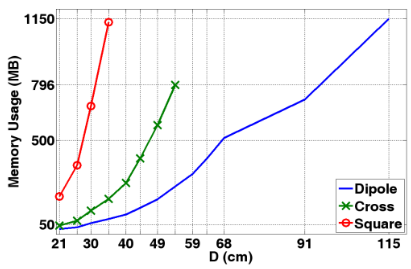

Fig. 15. Peak memory usage vs. *N*.

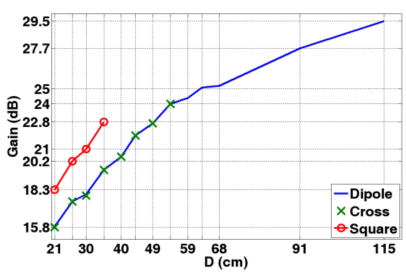

Fig. 16. Gain vs. *D*.

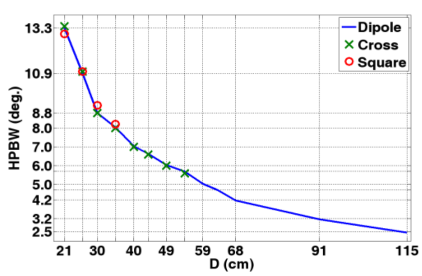

Fig. 17. Half-power beam-width vs. *D*.

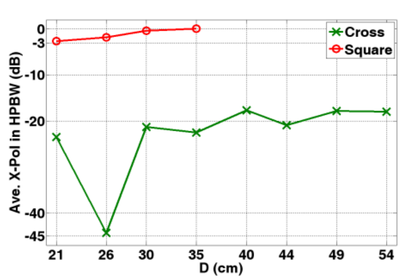

Fig. 18. Average X-pol in HPBW vs. *D*.

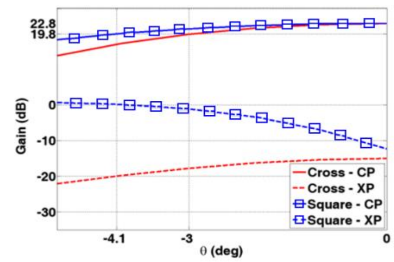

Fig. 19. Co-pol (CP) and X-pol (XP) gain patterns.

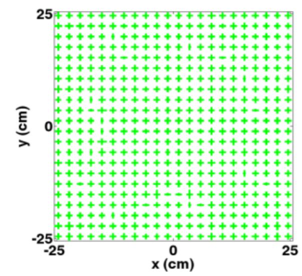

Fig. 20. MRA layout for D = 49 cm and cross elements.

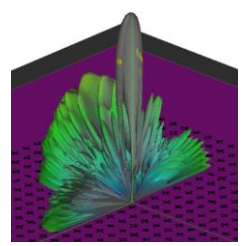

Fig. 21. Radiation pattern for D = 49 cm in dB.

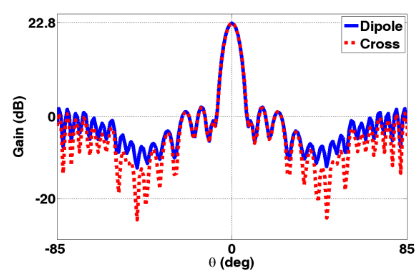

Fig. 22. Gain patterns for MRAs with D = 49 cm.

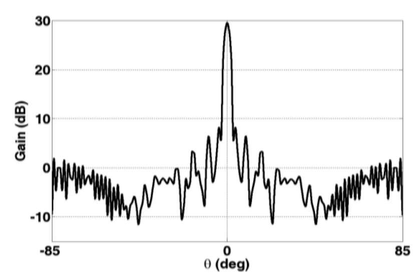

Fig. 23. Predicted gain pattern for MRA with D = 115 cm and unbalanced cross elements.

VI. CONCLUSION

Low-cost antenna architectures can be realized for dual-polarized commercial point-to-point wireless bridges using pure microstrip reflectarray antennas based on FR4 epoxy. A 2×2 array of square patches on a FR4 substrate can be used as a feed antenna for each of the link polarizations. Such a feed provides sufficient pattern symmetry and low cross-polarization. Rectangular dipole, unbalanced cross and square patches as reflector elements are demonstrated to be responsive for providing desired specifications. Cross elements can provide about 20 dB more polarization purity compared to square elements. However, square elements provide about 3 dB more gain compared to dipole and cross elements. Co-pol radiation pattern using dipole and cross elements are essentially the same. Half-power beam-width depends on the reflector diameters and not on the shape of reflector elements. Computational cost for designs based on dipole elements is considerably less than the others. The performance of MRAs based on square and cross elements can be well predicted from corresponding dipole designs.

REFERENCES

[1] J. Huang and A. Encinar, *Reflectarray Antennas*, New York: IEEE/John Wiley, 2008.

[2] *PTP Solutions Guide Motorola Fixed Point-to-Point Wireless Bridges*, Motorola Inc., 2008.

[3] *Cambium PTP 500 and PTP 300 Series User Guide*, Cambium Networks, 2012.

[4] Y. Pan, Y. Zhang, and S. Karimkashi, "Broadband low-cost reflectarray for multi-mission radar applications," *IEEE Radar Conference (RADAR)*, Atlanta, GA, pp. 613-617, 2012.

[5] J. Ethier, M. R. Chaharmir, J. Shaker, and D. Lee, "Development of novel low-cost reflectarrays," *IEEE Antennas Propagat. Mag.*, vol. 54, no. 3, pp. 277-287, 2012.

[6] L. Haitao, S. Gao, and L. Tian-Hong, "Low cost beam switchable reflectarray antenna," *Int. Workshop Smart Antennas (WSA)*, Dresden, pp. 8-11, 2012.

[7] E. Carrasco, M. Barba, J. A. Encinar, and M. Arrebola, "Design, manufacture and test of a low-cost shaped-beam reflectarray using a single layer of varying-sized printed dipoles," *IEEE Trans. Antennas Propagat.*, vol. 61, no. 6, pp. 3077-3085, 2013.

[8] K. Zhang, L. Jianzhou, W. Gao, and X. Jiadong, "Low-cost single-layer broadband reflectarray for satellite communications," *Antennas Propagat. Conf. (LAPC)*, Loughborough, pp. 78-83, 2013.

[9] K. Zhang, F. Yangyu, X. Jiadong, and Q. Chen, "Design of broadband, low cost single layer reflectarray using phoenix cell," *IEEE Region 10 TENCON Conf.*, Xi'an, pp. 1-4, 2013.

[10] G. Carluccio, A. Mazzinghi, and A. Freni, "Low cost complementary reflectarray for transportable radar applications," *ICEAA Conf.*, Palm Beach, pp. 723-725, 2014.

[11] Q. Wang, H. S. Zhen, C. J. Yu, and L. K. Peng, "Broadband low-cost reflectarray using modified double-square loop loaded by spiral stubs," *IEEE Trans. Antennas Propagat.*, vol. 63, no. 9, pp. 4224-4229, 2015.

[12] D. R. Prado, A. Campa, M. Arrebola, M. R. Pino, J. A. Encinar, and F. Las-Heras, "Design, manufacture and measurement of a low-cost reflectarray for global earth coverage," *IEEE Antennas Wireless Propagat. Lett.*, vol. 14, pp. 1-4, 2015.

[13] W. L. Stutzman and G. A. Thiele, *Antenna Theory and Design*, John Wiley, 1998.

[14] J. Huang, "Analysis of a microstrip reflectarray antenna for microspacecraft applications," *JPL TDA Progress Report*, no. 42-120, February 15, 1995.

[15] J. C. Rautio, "The microwave point of view on software validation," *IEEE Antennas Propagat. Mag.*, vol. 38, no. 2, pp. 68-71, 1996.

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