Advanced applications using dual-frequency and dual-polarization reflectarrays

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***Abstract*— Some advanced applications based on the reflectarray properties of independent beamforming at two frequencies and two polarizations are presented in this communication. The applications include reflectarray configurations for generating multi-spot coverages with a reduced number of antennas in geostationary satellites, High Gain Antennas for CubeSats and reflectarray panels to eliminate "blind zones" in the deployment of millimeter-wave 5G networks.**

***Index Terms*— Reflectarrays, multi-beam antennas, satellite antennas, multispot coverage, CubeSat antennas, dual-frequency reflectarrays, Reconfigurable Inteligent Surfaces.**

I. Introduction

A reflectarray is a periodic array of phasing cells, which are individually tuned to redirect and shape the reflected electromagnetic waves. Reflectarrays, contrary to reflector antennas, offer the possibility of independent beamforming for each polarization in multi-frequency operation, by using reflectarray cells with various conductive printed elements that are adjusted to provide a different phase-shift for each frequency and polarization, see Fig. 1. The flexibility of reflectarrays to operate at different frequencies [1] and polarizations [2] offers new capabilities for a wide range of advanced applications in future communications systems. Several implementations that can benefit from this unique property of reflectarrays are presented for satellite antennas and 5G communications networks.

Current High Throughput Satellites (HTS) generate about one hundred overlapped beams with a reuse scheme based on the combination of two frequencies and two orthogonal polarizations (four colors), to provide a multispot coverage for broadband internet access, see Fig. 2. A common solution for generating the four-color coverages consists of four reflectors (one for each color), operating in transmission (20 GHz) and reception (30GHz) [3]. In this communication, we present different solutions to reduce the four reflectors larger than 2 meters to only two reflectarray antennas of smaller dimensions (1.8 -m).

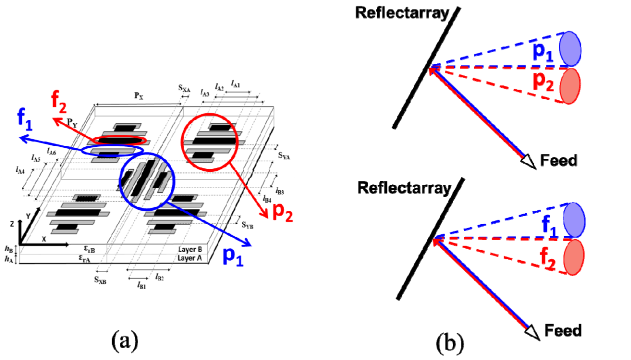


Fig. 1. Reflectarray to discriminate in frequency and polarization. (a) Reflectarray cells. (b) Generation of independent beams at each frecuency and polarization.

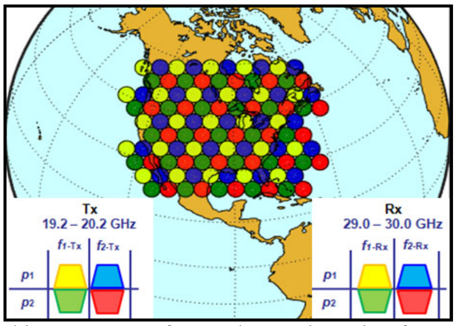


Fig. 2. Multispot coverage for North America using four colors with frequency and polarzation reuse

Reflectarray technology has been successfully demonstrated for High-Gain-Antennas (HGA) in small satellites, particularly for CubeSats, as in ISARA [4] and MARCO [5] missions. One of the main advantages is the ease for orbit deployment, similarly to solar panels. The feasibility of reflectarrays to convert dual linear polarization (LP) into dual circular polarization (CP) at multiple frequencies, allows to design broadband polarizer antennas, as a standard component for CubeSats, covering the whole X or Ka band for data transmission, as will be shown later in this communication.

A recent application of reflectarrays is their use as Reconfigurable Intelligent Surfaces (RIS) [6] to solve the problem of “blind zones” produced by obstacles in millimeter-wave (mm-Wave) 5G networks. These surfaces should be designed in dual-LP to support multi-user massive MIMO by exploiting the polarization diversity, and can be designed to generate different coverages in two frequency bands, as 28 GHz and 39 GHz. A representative example will be shown in this communication.

II. Multi-Beam Reflectarray antennas for High Throughput Satellites

Three different configurations using reflectarray antennas are proposed to provide a four-color multi-spot coverage to transmit (Tx) and receive (Rx) in Ka band, which allows to reduce the conventional four reflectors to only two antennas.

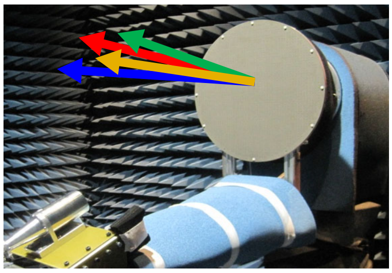
A. Antenna that Generates Four Beams per Feed

The first antenna configuration is based on a single offset flat reflectarray able to produce a complete four-color multispot coverage only for the Tx or Rx link. Therefore, two reflectarray antennas will suffice to produce the final coverage, one antenna working at Tx, and the other at Rx.

The reflectarray antenna is designed to generate four adjacent beams per feed in a different frequency-polarization combination (color). The feed position is selected to produce two adjacent beams in different frequencies according to the beam-squint effect, which ensures a minimum phase variation between the phase distributions at the two frequencies. The other two beams in orthogonal polarization are generated by implementing a different phase-shift for each linear polarization. A 43-cm demonstrator [7] has been designed, manufactured and tested with satisfactory results, see Fig. 3. The proposed concept has been applied to design a 1.8-m reflectarray antenna fed by 27 feeds to generate the 108 beams shown in Fig. 2, alternating in frequency (f1=19.45 GHz, f2=19.95 GHz) and polarization. The beams are generated in orthogonal LP, because of the simplicity, but the technique can be used to generate adjacent beams in orthogonal CP by using other types of cells combined with the Variable Rotation Technique (VRT) to separate the beams in circular polarization, as described in the patent [8].

B. Parabolic Reflectarray that Generates Two Beams per Feed in Orthogonal CP at Two Frequencies.

A 90-cm parabolic reflectarray has been demonstrated to generate two beams per feed in orthogonal CP, operating at two frequency bands (19.7 GHz for transmission and 30 GHz for reception) [9], see Fig. 4. The orthogonal CP beams were separated by applying the VRT independently to the printed parallel dipoles and arcs of the reflectarray cells shown in the inset of Fig. 4.a, as described in [10]. Furthermore, an optimization procedure was applied to reduce the cross-polarization in both Tx and Rx bands. The measured radiation patters are shown in Fig. 4 for three feeds (named as 2, 7 and 9) operating in dual-CP, and two



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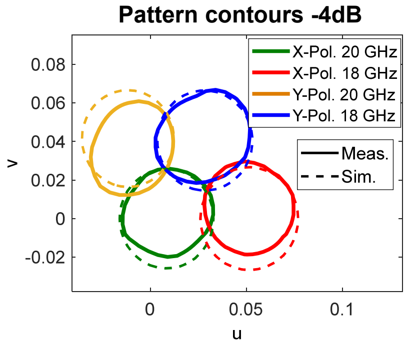

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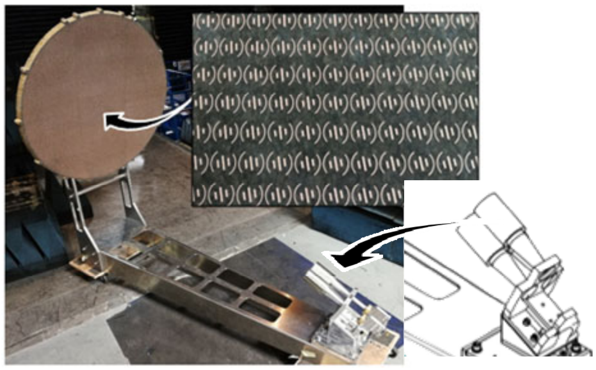
Fig. 3. Reflectarray that generates four beams per feed at different frequencies and polarizations. (a) 43-cm demonstrator. (b) Measured and simuated radiation patterns.



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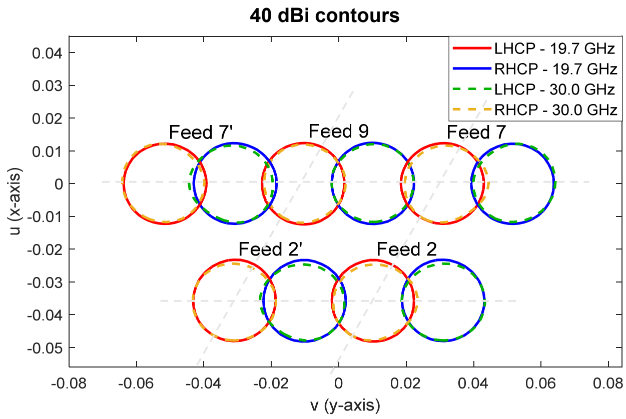

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Fig. 4. Parabolic reflectarray that generates two beams per feed at Tx and Rx frequencies. (a) 90-cm demonstrator. (b) Measured gain contours for beams generated by five feeds.

additional feeds placed in the symmetrical position (2' and 7'). A 1.8-m parabolic reflectarray has been designed to generate one half of the spot-beams shown in Fig. 2 (54 beams with 27 feeds). The results are satisfactory and validate the concept of generating two spaced beams in orthogonal CP by a single feed, changing the polarization of the beam in Tx and Rx.

C. Dual Reflectarray Configuration to Generate a Spot-Coverage.

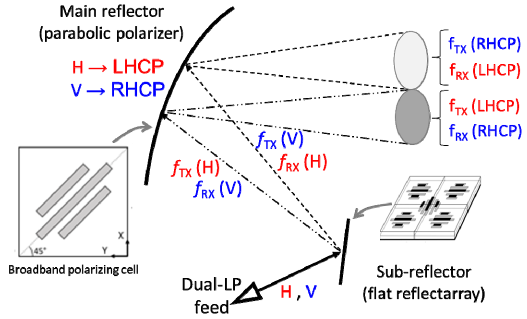
Another alternative to generate a complete multi-spot coverage in Tx and Rx with only two antennas is to use a dual-reflectarray configuration composed of a flat reflectarray that separates the beams in linear polarization and a parabolic main reflectarray that converts dual-linear into dual-circular polarization, with capability to introduce additional phase-corrections. Fig. 5 shows the antenna configuration and the simulated beams generated by a 1.8-m parabolic polarizer reflector with a flat reflectarray and 27 feeds, which generates half of the spot-beams shown in Fig. 2.

III. High-Gain Antennas for CubeSats

A high-gain polarizer reflectarray antenna of 28 cm × 28 cm has been designed for wideband communications in X band from 3U CubeSats, as shown in Fig. 6. The reflectarray is formed by 17 × 17 unit-cells consisting of two layers with orthogonal sets of three parallel dipoles. The printed dipoles are rotated 45º respect to the principal planes of the reflectarray. The dipole lengths are adjusted to collimate the reflected beam for the components of the incident field in the direction of the dipoles, as in conventional reflectarrays. However, in this work the reflectarray is designed to introduce a phase shift of 90º in one component of the reflected field respect to the other, in order to transform the dual-linearly polarized incident field into a dual-circularly polarized reflected field, while focusing a high gain beam in the direction $\theta_b = 23°$, $\varphi_b = 0°$. The polarizer reflectarray was first designed at central frequency and then, optimized by adjusting the lengths of the dipoles on each cell, to ensure a 90º phase-shift in the whole X-band. The simulated Axial Ratio (AR) for the optimized antenna, shown in Fig. 6.b, shows an excellent performance from 7 to 14 GHz with an axial ratio below 3 dB.

IV. Reflectarray Technology for Smart Reflecting Surfaces in mm-Wave 5-G

Dual-frequency and dual-polarization reflectarrays can be integrated into 5G and future-generation wireless networks as Reconfigurable Intelligent Surfaces (RIS) to address the problem of "blind zones" produced by obstacles. Passive RIS are designed to illuminate the blind zone by redirecting and shaping the reflected beam received from a nearby Base Station (BS), by using a phase-only pattern synthesis. The reflectarray based RIS can be deployed at reduced cost, with low visual impact (installed on walls or ceilings) and without



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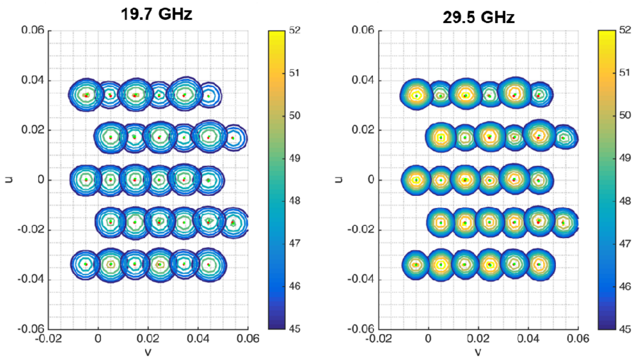

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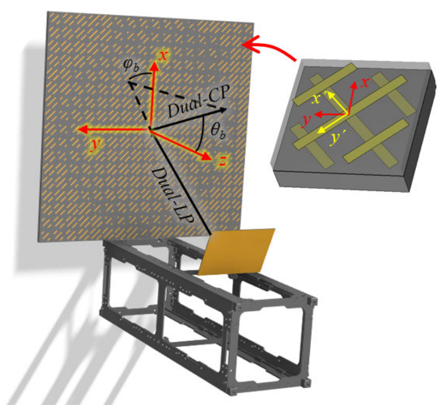
Fig. 5. Dual reflectarray antenna. (a) Antenna configuration. (b) Simulated beams at Tx and Rx frequencies.



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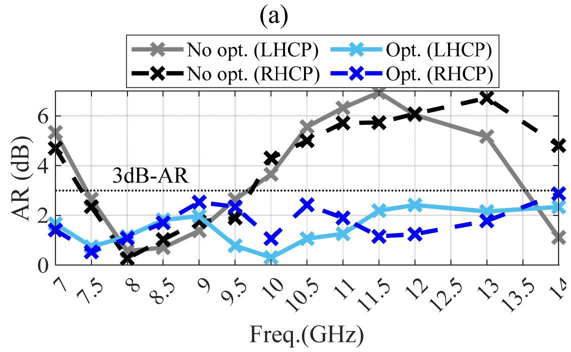

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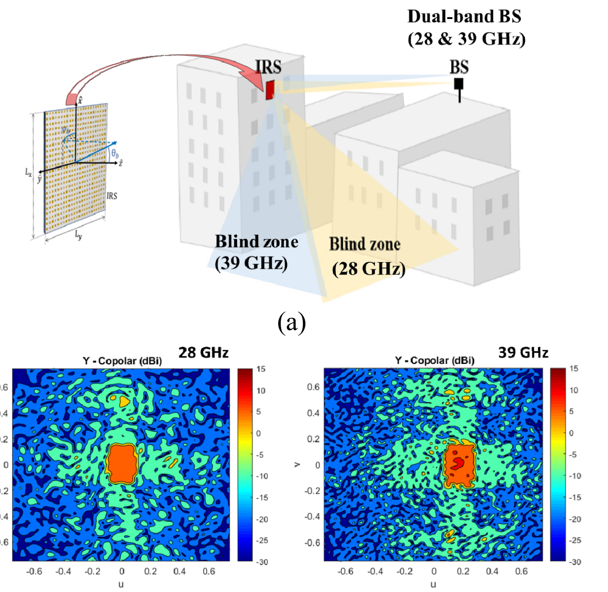
Fig. 6. High-gain polarizer reflectarray antenna covering the whole X-band for 3U Cubesats. (a) Antenna configuratin. (b) Simulated AR.

requiring any energy supply. Several reflectarray panels have been designed using a single layer of printed dipoles. The reflectarray cells are made of two orthogonal groups of parallel dipoles (each one controlling the phase-shift of one field component), which are separated diagonally half-a-period to be accommodated in a single layer. The dipole lengths in each orthogonal group are adjusted to ensure the same coverage for both polarizations under large angles of incidence. A reflectarray-based RIS has been designed to generate different coverages at 28 GHz and 39 GHz (see Fig. 7.a) when illuminated by base stations in the same location. A two-layer reflectarray with the cells shown in Fig. 1.a. is used to adjust the phase-shift (and the coverage) independently at each frequency band. The dipoles on the lower layer are used to control the phase at the lower frequency, while those on the upper layer are used to define the coverage for the higher frequency. The simulated coverages produced by the RIS in each frequency band are shown in Fig. 7.b. These results are very promising to avoid a prohibitive number of base stations in the future deployment of mm-wave 5G networks using different frequency bands.



(a)

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Fig. 7. Reflectarray panels as RIS for dual frequency operation in mm-wave 5G. (a) RIS configuration. (b) Simulated coverage at 28 GHz and 39 GHz.

V. CONCLUSIONS

Different applications of dual-frequency and dual-polarization reflectarrays have been presented with satisfactory results. Three antenna configurations have been shown to generate a complete multispot coverage from GEO satellites with only two reflectarrays of 1.8-m instead of the conventional 2.3-m reflectors. A broadband HGA that generates CP has been designed as a standard device for 3U CubeSats covering the whole X-band. Finally, a dual frequency smart reflecting surface (usually called RIS) has been designed to generate specific coverages in each frequency band. Those results demonstrate the potential of reflectarray technology in the development of antennas and smart reflecting surfaces for advanced terrestrial and satellite communications.

ACKNOWLEDGMENT

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REFERENCES

[1] T. Smith, U. Gothelf, O. S. Kim and O. Breinbjerg, "Design, Manufacturing, and Testing of a 20/30-GHz Dual-Band Circularly Polarized Reflectarray Antenna," in IEEE Antennas and Wireless Propagation Letters, vol. 12, pp. 1480-1483, 2013.

[2] J. A. Encinar, L. Datashvili, J. Agustín Zornoza, M. Arrebola, M. Sierra–Castañer, J. L. Besada, H. Baier, H. Legay “Dual–Polarization Dual–Coverage Reflectarray for Space Applications”, IEEE Trans. on Antennas and Propagation, 54(10), 2006, 2827–2837.

[3] M. Schneider, C. Hartwanger and H. Wolf, “Antennas for multiple spot beams satellites”, CEAS Space Journal, Vol. 2, pp. 59-66, 2011.

[4] R. E. Hodges, M. J. Radway, A. Toorian, D. J. Hoppe, B. Shah and A. E. Kalman, "ISARA - Integrated Solar Array and Reflectarray CubeSat deployable Ka-band antenna," 2015 IEEE International Symposium on Antennas and Propagation (APS-URSI), Vancouver, BC, Canada, 2015, pp. 2141-2142.

[5] R. E. Hodges, N. Chahat, D. J. Hoppe and J. D. Vacchione, "A Deployable High-Gain Antenna Bound for Mars: Developing a new folded-panel reflectarray for the first CubeSat mission to Mars," IEEE Antennas Propag. Magazine, vol. 59, no. 2, pp. 39-49, April 2017.

[6] Vaquero, Á. F. et al., "Reflectarray-based Intelligent Reflecting Surface to Improve mm-Wave 5G coverage in outdoor scenarios," 2022 IEEE Intl. Symp. on Antennas and Propagation (AP-S/URSI), Denver, CO, USA, 2022, pp. 794-795.

[7] D. Martinez-de-Rioja, E. Martinez-de-Rioja, J. A. Encinar, R. Florencio, and G. Toso, “Reflectarray to generate four adjacent beams per feed for multispot satellite antennas,” IEEE Trans. Antennas Propag., vol. 67, no. 2, pp. 1265– 1269, Feb. 2019.

[8] R.R. Boix, R. Florencio, J.A. Encinar, D. Martínez de Rioja and E. Martínez de Rioja, “Antena reflectarray plana multi-banda con separación de haces de polarización circular y método para su diseño”. Patent ES202230926A, priority 2022-10-27.

[9] D. Martinez-de-Rioja et al., “Transmit–Receive Parabolic Reflectarray to Generate Two Beams per Feed for Multispot Satellite Antennas in Ka-Band,” IEEE Trans. Antennas Propag., vol. 69, no. 5, pp. 2673-2685, May 2021.

[10] D. Martinez-de-Rioja, R. Florencio, J. A. Encinar, E. Carrasco, Rafael R. Boix, “Dual Frequency Reflectarray Cell to Provide Opposite Phase-Shift in Dual Circular Polarization with Application in Multibeam Satellite Antennas”, IEEE Antennas Wireless Propag. Letters, vol. 18, no. 8, pp. 1591-1995, Aug.. 2019.