Preliminary Results on the Feasibility of Flexible Space-Fed Antennas

Original
Preliminary Results on the Feasibility of Flexible Space-Fed Antennas / Massaccesi, A.; Beccaria, M.; Pirinoli, P.. - (2024), pp. 2551-2552. (2024 IEEE International Symposium on Antennas and Propagation and INC/USNCURSI Radio Science Meeting, AP-S/INC-USNC-URSI 2024 Firenze (Ita) 14-19 July 2024) [10.1109/ap-s/inc-usnc-ursi52054.2024.10686527].

Availability:
This version is available at: 11583/3000904 since: 2025-06-14T12:04:11Z

Publisher:
IEEE

Published
DOI:10.1109/ap-s/inc-usnc-ursi52054.2024.10686527

(Article begins on next page)

Preliminary results on the feasibility of flexible space-fed antennas

A. Massaccesi, M. Beccaria, and P. Pirinoli
Politecnico di Torino, Dept. of Electronics and Telecomm., 10129 Torino, Italy

***Abstract*—In this communication, the feasibility of space-fed antennas as Transmitarrays or Reflectarrays, where the focusing transmitting/reflecting surface is flexible, is investigated, with the aim of obtaining configurations providing almost the same radiating features even when they are conformal to cylinders with different radii of curvature. Preliminary numerical results on both a reflectarray and a transmitarray confirm the possibility to realize such antennas.**

I. Introduction

In the past decades, space-fed antennas as Reflectarrays (RAs) and Transmitattays (TAs) were identified as good alternatives to bulkier structures, as conventional reflectors or more complex configurations as phased arrays, since they combine the simplicity of the feeding system with the flatness of the reflecting/transmitting surface. Recently, the increasing demand for systems suitable for being installed on mobile platforms or for being integrated with wearable systems, requires that the antenna is able to provide also some degree of flexibility. The design of such an antenna is challenging from two different points of view: the need to keep as much as possible stable the antenna performance when it is bent and the necessity to use proper materials for its manufacturing. For what concerns this second aspect, the introduction of flexible materials that can be used as substrates or to realize the reflecting/transmitting surface in case of RAs and TAs using a 3D-printing technique, could represent a possible solution. Relatively to the radiation requirements, some results on the design of conformal RAs [2]–[5] or TAs [6]–[9] manufactured adopting different materials and techniques, confirm the possibility of realizing configurations with good performance, but the possibility to design a configuration able to provide almost the same radiation features even when the surface curvature to which they are conformed changes has never been considered. Viceversa, here the design of a reflectarray and a transmitarray that keep good radiating characteristics even when they are bent, is investigated. In both the cases, the obtained preliminary results confirm the antenna feasibility.

II. Dielectric conformal Reflectarray

The considered RA unit-cell (UC) was early introduced in [10] to design a planar dielectric reflectarray, while in [5] it was exploited to implement convex configurations. It is a dielectric-only structure, realized using FDM techniques and PREPERM® ABS1000 material, nominally characterized by $\varepsilon = 10$ and $\tan\delta = 0.004$. The high dielectric constant allows a reduction of the UC thickness that makes possible an increase of the reflectarray flexibility. The unit-cell, optimized to work at $f_0 = 30\,\mathrm{GHz}$, has a size $L = 3\,\mathrm{mm} = 0.3\lambda_0$ and consists in a dielectric cylindrical resonator situated on a thin grounded square slab. The reflection coefficient S_{11} is controlled by the diameter d of the cylinder that varies between $1\,\mathrm{mm}$ and $2.8\,\mathrm{mm}$ corresponding to a range of approximately $330°$ for $\angle S_{11}$, while the heights of the cylinder and of the base are constant and such that the total height of the UC is $H_T = 0.31\lambda_0$.

The UC is used to design an RA able to perform in almost the same way when it is bent to cylinder with different curvature radii. Taking inspiration from the bifocal approach, the Bi-Curvature Method (BCM) is proposed, according to which the actual phase distribution on the RA surface is a linear combination of the two distinct phase distributions required to compensate the phase of the incident field for two RAs with two different radii of curvature:

$$\Phi_{BCM} = \frac{\Phi_{Rc_1} + \Phi_{Rc_2}}{2} \tag{1}$$

where Φ_{Rc_1} and Φ_{Rc_2} are the phase distributions required when the reflectarrays have the curvatures Rc_1 and Rc_2, respectively.

As an example, a square-shaped 51×51 convex reflectarray with a side length of $D = 15.3\lambda_0$ is designed by considering $Rc_1 = 25\lambda$ and $Rc_2 = 45\lambda$. The offset feed horn [3] is located at a distance from the RA equal to $1.1D$ and in a position such that its radiated field impinges on the reflecting surface with an angle $\theta_f = -20°$. The direction of maximum re-radiation is specular to the incident one. The resulting phase distribution Φ_{BCM} is plotted in Fig.1a.

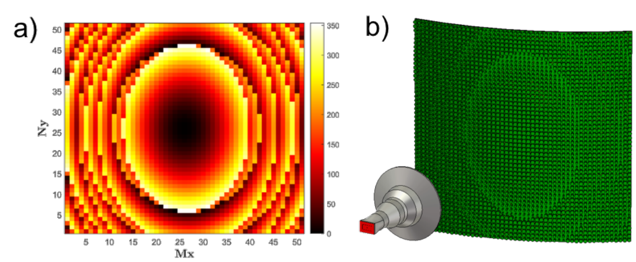

Fig. 1. a) Required phase distribution. b) Antenna configuration when the RA is bent to a cylinder with $R = 25\lambda$

Two configurations, named CRA$_1$ (sketched in Fig. 1b) and CRA$_2$ in the following, obtained bending the (same) RA with radius Rc_1 and Rc_2 are analyzed with CST Microwave Studio and their radiation patterns in both the H- and E-planes are shown in Fig. 2. Thanks to the BCM design approach, they are very similar: the maximum gain differs for 0.2 dB, the

SLL is the same in the E-plane (≈-15.4 dB), where the effect of the curvature is stronger, while in the H-plane the SLL of CRA_1 is 2 dB lower than for CRA_2.

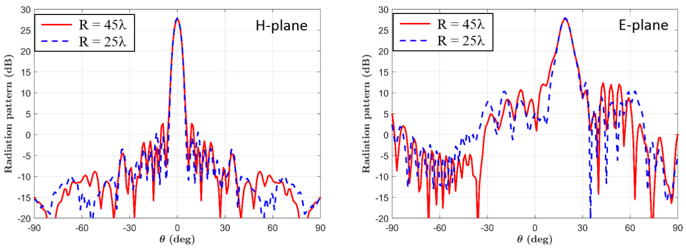

Fig. 2. Radiation patterns provided by the reflectarray designed with the BCM approaches and bent with 2 different radii of curvature. Left: H-plane; right: E-plane.

III. Flexible Transmitarrays

The performed analysis in the case of the transmitarray is focused on the design of a proper unit-cell, able to guarantee good performance and flexibility. The analysis of several possible configurations identifies as a promising solution the UC sketched in the inset of Fig. 3. It consists of three layers of Kapton ($\epsilon_r = 3.4$, $tan\delta = 0.0018$), each 0.1 mm thick, alternated with two Rohacell layers characterized by $\epsilon_r = 1.048$, $tan\delta = 0.0135$ and thickness equal to $\lambda/4 = 2.6$ mm at 28.75 GHz; the cells periodicity is $\lambda/2$. On each layer of Kapton a Malta Cross is printed, and its size L is varied to control the transmission coefficient S_{21}. Properly selecting the range of variation for L, more than 360° of phase can be provided while $|S_{21}|$ is never lower than 2 dB. Since for a TA the instance in which the transmitarray is planar represents the worst case, the UC has been adopted to design a configuration in which the focusing surface is planar, with side $D = 15\lambda \times 15\lambda$ and able to radiate a broadside pencil beam. The surface is illuminated by a centered feed array, located at a focal distance $F = 0.5$D, from the center of the TA, to achieve a more compact overall structure, whose radiation pattern can be modelled as $cos^{q_{E-H}}$ with $q_H = 8.8$ in the H-plane and $q_E = 6.3$ in the E-plane. The obtained configuration, sketched on the left of Fig. 3, has been analyzed with CST Microwave Studio; then, the transmitarray has been bent with a radius of curvature $R = 15.4\lambda$, keeping constant the distance F between the feed array and the TA center and the new configuration, shown on the right of Fig. 3, is in its turn simulated.

In Fig. 4 the radiation patterns, computed at 28.75 GHz, in the two principal planes are shown for both the configurations. In both the planes they are very similar each other. From their comparison, it emerges that the main beam is stable while the SLL stays no less than 16 dB below the maximum.

IV. Conclusion

In this communication, the feasibility of flexible space-fed antennas is investigated. Two different design and manufacturing approaches have been considered: a dielectric-only RA has been designed using the BCM technique, while the TA has been designed adopting a multi-layer unit-cell. The

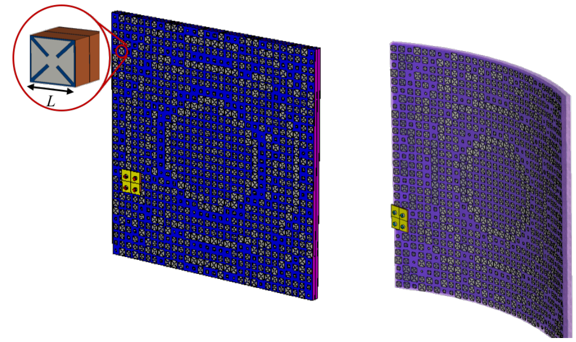

Fig. 3. Sketch of the designed TA in planar (left) and conformal configurations. Blow out: adopted multi-layer unit-cell.

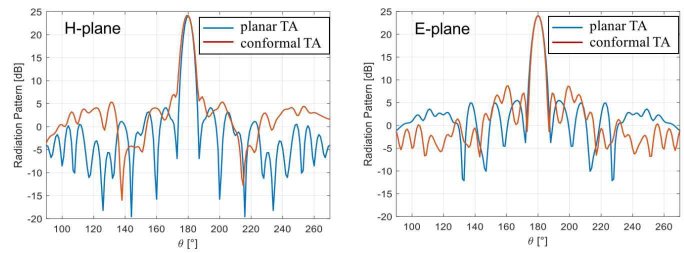

Fig. 4. Radiation patterns provided by the TA when it is planar or it is bent with a radius of curvature $R = 15.4\lambda$. Left: H-plane; right: E-plane.

results obtained from the numerical analysis of both the structures, where the curvature of the reflecting or transmitting focusing surface is modified, confirm the possibility to design antennas whose performance does not vary noticeably even when conformed to different supporting structures.

References

[1] D. J. Gregoire, "3-D Conformal Metasurfaces," *IEEE Antennas Wirel. Propag. Lett.*, vol. 12, pp. 233-236, 2013.

[2] M. Beccaria, P. Pirinoli, G. Dassano, M. Orefice, "Design and experimental validation of convex conformal reflectarray antennas," *Electronics Letters*, vol. 52, no. 18, pp. 1511–1512, Aug. 2016.

[3] M. Beccaria, *et al.*, "Enhanced Efficiency and Reduced Side Lobe Level Convex Conformal Reflectarray," *Applied Sciences*, vol. 11, pp. 9893-9906, 2021.

[4] K. Xu, J.H. Choi, "Liquid-Metal-Tuned Patch Element for Flexible and Reconfigurable Reflectarrays/Intelligent Surfaces," *2021 IEEE Int. Symp. Antennas Propag.*, Singapore, 2021, pp. 79-80.

[5] A. Massaccesi, M. Beccaria, P. Pirinoli, "Preliminary Results on Convex Conformal Dielectric-based Reflectarrays," *2022 IEEE Ninth Int. Conf. Comm. Electronics (ICCE)*, Nha Trang, Vietnam, 2022.

[6] M. Beccaria, P. Pirinoli, F. Yang, "Preliminary results on Conformal Transmitarray Antennas", *2018 IEEE Int. Symp. Antennas Propag.*, Boston, MA, USA, 2018, pp. 265-266.

[7] Li-Zhao Song, Pei-Yuan Qin, Y. Jay Guo, "A High-Efficiency Conformal Transmitarray Antenna Employing Dual-Layer Ultrathin Huygens Element", *IEEE Trans. Antennas Propag.*, vol.69, no.2, pp.848-858, 2021.

[8] L. -Z. Song, P. -Y. Qin, H. Zhu, J. Du, "Wideband Conformal Transmitarrays for E-Band Multi-Beam Applications," *IEEE Trans. Antennas Propag.*, vol. 70, no. 11, pp. 10417-10425, 2022.

[9] L. -Z. Song, P. -Y. Qin, S. Maci, Y. J. Guo, "Ultrawideband Conformal Transmitarray Employing Connected Slot-Bowtie Elements," *IEEE Trans. Antennas Propag.*, vol. 69, no. 6, pp. 3273-3283, 2021.

[10] A. Massaccesi, M. Beccaria and P. Pirinoli, "High-efficiency Reflectarray Using Dielectric Resonator Elements," *2021 IEEE Int. Symp. Antennas Propag.*, Singapore, 2021, pp. 1595-1596.