

Smart Electromagnetic Skin with scanning capabilities

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Abstract—The proposed study explores the possibility of designing curved, passive Smart Electromagnetic Skins (SESS), working at millimeter waves, that could be integrated into a streetlight or traffic light pole and could provide beam scanning over a range slightly lower than 60° simply by its mechanical rotation around the pole. Numerical results confirm the effectiveness of the approach specifically developed for the design of the SES and the feasibility of a smart skin that provides reconfigurability while maintaining high simplicity and reduced cost.

I. INTRODUCTION

The foreseen characteristics of the next-generation communication systems, such as higher transmission speed and very low latency, make it necessary to define new paradigms for the network. While the use of mm-waves or sub-THz frequencies seems to be very promising due to the extremely high bandwidth that their use can guarantee, they suffer from higher losses, coming from different effects, such as free space propagation, building penetration and interaction with obstacles along the propagation path, that are responsible for the degradation of the coverage, especially in regions not in the line of sight (LOS). Taking into account the issue at hand and the need to minimize the complexity, cost, and power consumption of the network, the idea of considering in the design of the system the environment in which the propagation occurs as a further degree of freedom has been recently introduced [1]. The implementation of such an environment is possible thanks to the introduction of several active and passive devices, generally named Smart Electromagnetic Skins (SESS): they are very thin surfaces able to provide a non-specular reflection to reach blind spots or cover desired areas. When they can also supply some reconfigurability, they are usually named Reconfigurable Intelligent Surfaces (RISs).

In [2], the feasibility of designing a curved SES that can be integrated into urban furniture instead of mounted on the wall of a building is proved through the numerical characterization of an SES designed to be located between a pole and a concentric radome. Despite the numerous advantages of such a configuration compared to the conventional use of a planar smart skin, it suffers from the limitation that its design is performed just for a specific direction of arrival of the incident field and for covering a predefined area. The straightforward solution to this drawback consists of inserting active components in the Unit Cells (UCs) adopted for discretizing the SES,

with a consequent increase in its complexity and cost. Taking inspiration from what has been done in the case of passive reflectarrays or transmitarrays [3] - [7], in which scanning is achieved by moving the feed relative to the reflecting or transmitting surface, a design technique has been developed, and here proposed. It allows us to change the direction in which the SES refocuses the incident field, radiated by the base station whose position is fixed, simply by rotation of the SES itself around the pole on which it is mounted. The preliminary numerical results summarised in the following confirm the effectiveness of the proposed approach and the feasibility of a passive skin with scanning capabilities.

II. DESIGN APPROACH

Let us consider the structure shown in Fig. 1a. It consists of several layers concentric to the pole on which the SES is mounted. The inner layer is the metasurface itself, whose design is carried out following the procedure summarized in the following; above it, a layer made of *Lexan*TM that is a material usually adopted for radomes, characterized by $\epsilon_r = 2.8$ and $\tan \delta = 0.01$, is located: notice that the design of the smart skin is performed taking directly into account the presence of this cover. Finally, a metallic screen partially surrounds the layers underneath so that only their uncovered portion is illuminated by the incident field. The metasurface is divided into several regions (e.g., 5) having different functions. Assuming that they are numbered starting from the leftmost, the portions of the SES with odd numbers are designed to point in different directions, while those labeled with even numbers act as a transition between those nearby and are designed by

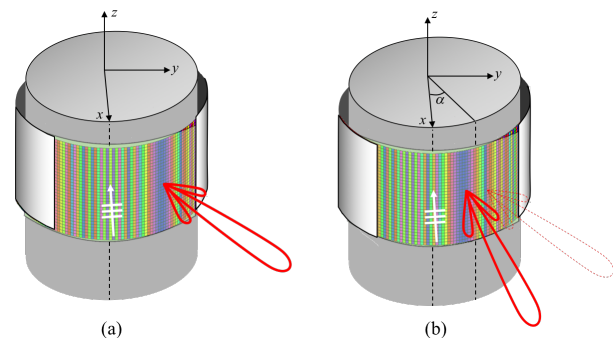


Fig. 1. a) structure of the proposed reconfigurable skin mounted on a pole. b) configuration obtained rotating of an angle α the SES around the pole.

resorting to a bifocal approximation [5,6]. If the metasurface is rotated by an angle α around the pole and the screen is not moved, a different portion of the SES is illuminated, and the reradiated field points in a different direction, as schematically shown in Fig. 1b.

III. PRELIMINARY NUMERICAL RESULTS

The approach summarized in the previous section is tested through its application to the design of different smart skins to settle the optimal size of the different regions and the transition ones in particular. By increasing the size of the transition regions, the performance of the SES in correspondence of pointing angles close to the lower and upper bound of the scanning range improves, but at the cost of decreasing the maximum RCS in the center of the scanning range.

In the following, some preliminary results are shown; they are related to an SES designed to cover an angular scanning range characterized by $-25^\circ < \varphi_{max} < 35^\circ$ and $\theta = 100^\circ$ in the reference system in Fig. 1 when an incident plane wave with $(\theta_{inc} = 90^\circ, \varphi_{inc} = 180^\circ)$ impinges on it. The SES is discretized with 150×40 UCs, having a size slightly less than $\lambda_0/3$ at the design frequency $f_0 = 27$ GHz. The unit cell, shown in Fig. 2, consists of a layer of Diclady527 ($\epsilon_r = 2.55$, $\tan \delta = 0.0022$) with thickness $h = 0.508$ mm, located over the groundplane. On the top, it presents a square patch with a cross-shape slot in the center; above this, there is the layer of *Lexan*TM ($\epsilon_r = 2.8$, $\tan \delta = 0.01$) with a thickness of 1 mm. The side W of the patch is the geometrical degree of freedom used to control the behavior of the unit cell. The number of

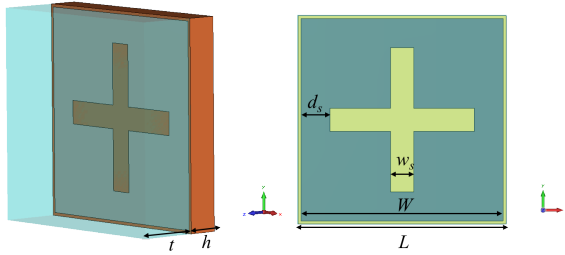


Fig. 2. Sketch of the unit cell with the integrated radome.

unit cells not hidden by the screen is equal to 84×40 , while the central region of the SES, consisting in 63×40 is designed to point to a direction characterized by $(\varphi = 20^\circ, \theta = 100^\circ)$ when $\alpha = 0^\circ$. The phase delay map not behind the screen in the case $\alpha = 0^\circ$ is shown in Fig. 3. In Fig. 4 it is shown the angular variation of the RCS in the cut $\theta = 100^\circ$ obtained through the PO analysis of the SES, at the design frequency and for different α values, separated from each other by about 3.5 degrees. The results highlight that inside the considered scanning range the RCS pattern is characterized by a well defined main beam and a variation of the maximum RCS not larger than 2 dB, while SLL stays always below -9 dB.

ACKNOWLEDGEMENT

This work was supported by the European Union - Next Generation EU under the Italian National Recovery and Resilience Plan (NRRP), Mission 4, Component 2, Investment

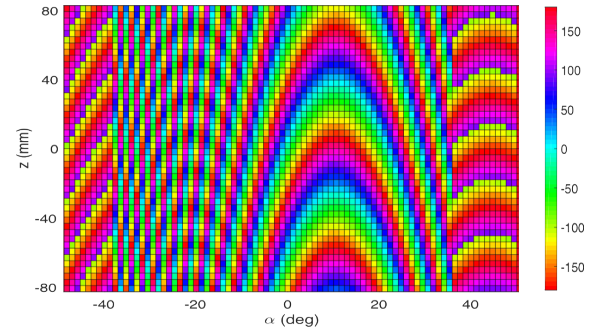


Fig. 3. Phase delay map required by the portion of the smart skin not hidden by the metallic screen for $\alpha = 0^\circ$.

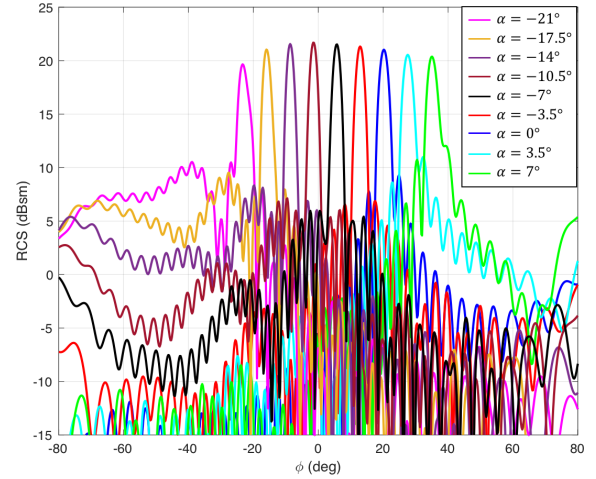


Fig. 4. RCS evaluated at the design frequency for different values of the rotation angle α .

1.3, CUP E13C22001870001, partnership on Telecommunications of the Future (PE00000001 - program RESTART).

REFERENCES

- [1] E. Martinez-de-Rioja, A.F. Vaquero, M. Arrebola, E. Carrasco, J.A. Encinar, M. Achour, "Passive intelligent reflecting surfaces based on reflectarray panels to enhance 5G millimeter-wave coverage," *Int. J. Microw. Wirel. Tech.* 2022.
- [2] A. Freni, M. Beccaria, A. Mazzinghi, A. Massaccesi, P. Pirinoli, "Low-Profile and Low-Visual Impact Smart Electromagnetic Curved Passive Skins for Enhancing Connectivity in Urban Scenarios," in *Electronics*, 2023.
- [3] G. -B. Wu, S. -W. Qu and S. Yang, "Wide-Angle Beam-Scanning Reflectarray With Mechanical Steering," in *IEEE Trans. Ant. Propag.*, 2018.
- [4] P. Pirinoli, A. Massaccesi and M. Beccaria, "Application of the MmCn-BBO algorithms to the optimization of antenna problems," *Int. Conf. on Electromag. in Adv. App. (ICEAA)*, 2017.
- [5] P. Nayeri, F. Yang and A. Z. Elsherbeni, "Bifocal Design and Aperture Phase Optimizations of Reflectarray Antennas for Wide-Angle Beam Scanning Performance," in *IEEE Trans. Ant. Propag.*, 2013.
- [6] Y. Cui, R. Bahr, S. A. Nauroze, T. Cheng, T. S. Almonneef and M. M. Tentzeris, "3D Printed "Kirigami"-Inspired Deployable Bi-Focal Beam-Scanning Dielectric Reflectarray Antenna for mm-Wave Applications," in *IEEE Trans. Ant. Propag.*, 2022.
- [7] P. Pirinoli, T. Lohrey, M. Orefice, M. Beccaria and G. Dassano, "Beam Scanning Reflectarrays for DTH application: preliminary results," *13th Europ. Conf. Ant. Propag. (EuCAP)*, 2019.