

Beam-Scanning Curved Smart Electromagnetic Skins for Outdoor Scenarios

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Abstract

Curved passive Smart Electromagnetic Skins (SESs), integrated into a streetlight or traffic light pole, have already been introduced as suitable devices to improve the coverage performance of a communication network without increasing its complexity. Despite their several advantages, they were supposed to be designed to provide fixed coverage. Here, an innovative design technique is proposed, through which it is possible to change the pointing direction of the smart skin simply by its mechanical rotation around the pole on which it is mounted. Numerical results confirm the effectiveness of the developed approach and the feasibility of a smart skin that provides reconfigurability over an angular range of approximately 60° while maintaining high simplicity and reduced cost.

1 Introduction

The features of next-generation communication systems, which include increased transmission speeds and extremely low latency, necessitate the establishment of new network paradigms. While the use of mm-waves or sub-THz frequencies holds great promise due to their exceptionally high bandwidth, they are also affected by greater losses resulting from various factors, such as free space propagation, building penetration, and interaction with obstacles along the transmission path. These factors contribute to the deterioration of coverage, particularly in areas not in the line of sight (LOS). Considering this challenge and the need to reduce network complexity, cost, and power consumption, incorporating the environment where the propagation takes place has recently emerged as an additional degree of freedom in the system design [1, 2]. The establishment of such an environment is achievable through the deployment of various active and passive devices, collectively referred to as Smart Electromagnetic Skins (SESs) [3, 4]. They are ultra-thin surfaces, discretized with a suitable number of resonant or sub-wavelength Unit Cells (UCs) capable of producing non-specular reflections to address blind spots or cover specific areas. When these surfaces also include active components that can be controlled to achieve the reconfigurability of the smart skin, they are typically referred to as Reconfigurable Intelligent Surfaces (RISs).

In [5], the potential for designing a curved Smart Electromagnetic Surface (SES) that can be integrated into urban

furniture, rather than being mounted on building walls, is demonstrated through the numerical characterization of an SES intended for placement between a pole and a concentric radome. As many other planar solutions presented in the literature (see, e.g., [4]), the configuration in [5] is static, and only small adjustments can be made to change its pointing direction by a few degrees. A straightforward approach to address this limitation is obviously that of incorporating active components within the Unit Cells (UCs) used to discretize the SES, which would, however, lead to increased complexity and cost. The approach proposed here has been inspired by techniques developed in past years for the design of beam scanning passive reflectarrays or transmitarrays; in [6]-[11], several solutions have been presented, in which the reflecting or transmitting surface is properly designed and the scanning is achieved by moving the feed relatively to it. Since in the case of the SES the incident field is generated by the base station, whose position is fixed, the exploited idea consists of rotating the SES itself around the pole on which it is mounted, in such a way that a different portion of it is illuminated by the incident field. Clearly, such a solution is peculiar to curved SES and cannot be applied to planar configurations integrated into the walls of a building. 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.

2 Design procedure

To allow the possibility of scanning the beam through its mechanical rotation around the pole on which it is mounted, the developed procedure is based on the idea of splitting the smart skin into several regions with distinct behaviors. In the considered case their number is five, but a higher (odd) number of sections can also be considered. Differently from the configuration discussed in [5], the metasurface here is concentric with the pole and is partially covered by a metallic screen. The aperture in the screen defines the portion of the surface illuminated by the impinging field, referred to as the "visible window." When the metasurface is rotated by an angle α around the pole, the visible window shifts by the same angle in the opposite direction. This results in a different portion of the surface illuminated by the impinging field, whose direction of arrival remains fixed. 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 exploiting a bifocal approximation [8, 10].

As an example, consider the procedure for the design of a smart skin able to cover a scanning range for ϕ larger than 60° and pointing to $\theta = 110^\circ$, for which numerical results will be presented in Section 3 (the angles are defined in the reference coordinate system in the top plots in Fig. 1). The metasurface is discretized with 99×26 unit cells, having size slightly smaller than $\lambda/2$ at $f_0 = 27$ GHz. The central part of the surface is designed to point to $\phi_{max} = 0^\circ$, while the most external ones are designed to have maximum re-radiation in the proximity of the directions delimiting the scanning range. The number of cells contained in the visible window is 55×26 .

Fig. 1 shows the smart skin working principle. The configuration in the top left plot is relevant to $\alpha = 0^\circ$, where the portion of the SES not hidden by the screen is the one delimited in the below phase map by the continuous black box, representing the visible windows: it consists of the central part of the SES plus the two transition regions. Therefore, it must reflect the incident field in a direction characterized by $[\phi_{max} = 0^\circ, \theta_{max} = 110^\circ]$. The rotation of the SES of an angle $\alpha = -10.7^\circ$ corresponds to move the visible window in the opposite direction of the same amount. So, a different portion of the skin is illuminated and the reflected field will point toward a different direction, as demonstrated by the results summarized in the next section.

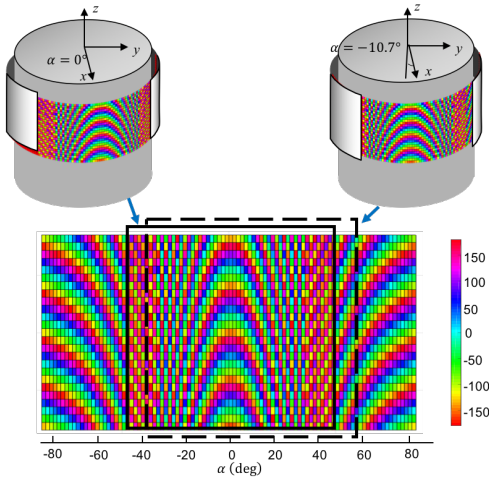


Figure 1. Top: Sketch of the smart skin mounted on the pole and partially hidden by the metallic screen. Left: configuration for $\alpha = 0^\circ$; right: configuration for $\alpha = -10.7^\circ$. Bottom: entire phase delay map, with the portions in the visible window for the two cases considered highlighted.

3 Preliminary Numerical Results

To verify the actual scanning capability of the SES whose design was described in the previous section, configurations

obtained for different values of the angle α were simulated. The considered unit cell is that already adopted in [5], and consists of a square metallic patch printed on a grounded dielectric DiClad527 substrate ($\epsilon_r = 2.55$, $\tan \delta = 0.0022$), $h = 0.8$ mm thick. Varying the side W of the patch is possible to control S_{11} ; in particular, if W varies in the interval $[1, 4]$ mm the phase of S_{11} covers a range of approximately 290° . At the same time, its magnitude is never lower than -0.5 dB.

To reduce the computational cost, only the configuration for $\alpha = 0^\circ$ that shows a symmetry along the xz plane is simulated with CST Microwave Studio. Because the obtained pattern is in very good agreement with that provided by a Physical Optics (PO) analysis of the SES (see the RCS patterns of Fig. 2 corresponding to $\alpha = 0^\circ$), the configurations obtained for other values of α have been carried out with the PO. The values of α considered are separated by about 5.35 degrees. Due to the symmetry of the problem, for the sake of readability, the variation of the RCS in the plane $\theta = 110^\circ$ obtained only for negative values of α is plotted in Fig 2. The curves for positive values of α are specular of those evaluated for negative values. The pointing angles and the values of the maximum RCS for the considered α angles are summarized in Table 1. Both the results in Fig. 2 and Table 1 highlight that the scanning range varies between -33° and 33° and in this range the RCS pattern is characterized by a well defined main beam while the variation of the maximum RCS is lower than 1 dB and the SLLs stay always below -9 dB.

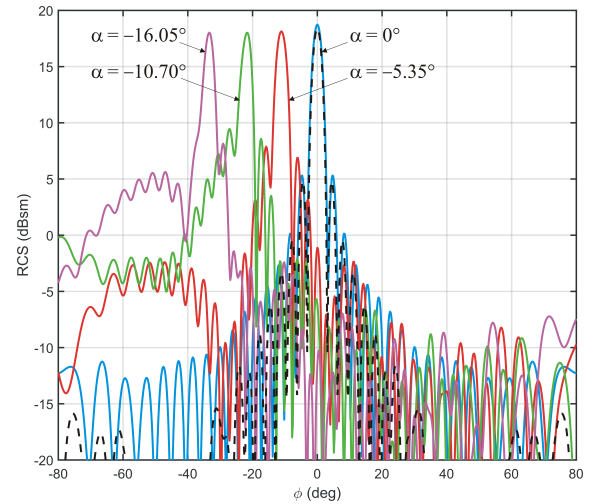


Figure 2. RCS evaluated at the design frequency f_0 for different values of the rotation angle α : (solid) PO simulation, (dash) CST simulation.

4 Conclusion

In this work, an innovative design procedure for the design of a curved passive smart skin with beam scanning capability is introduced and discussed. The numerical results confirm that the SES can actually point the main beam at

α	Pointing Angle φ_{max}	max RCS [dBm ²]
0°	0°	18.7
±5.35°	±11.3°	18.1
±10.7°	±21.8°	18.0
±16.05°	±33.5°	18.0

Table 1. Pointing direction and maximum RCS evaluated at the design frequency f_0 for different values of the rotation angle α .

directions characterized by different angles simply by its mechanical rotation around the pole on which it is mounted.

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