Influence of Dielectric Overlay Dimensions on Performance of Miniaturized ESPAR Antenna

M. Czelen, M. Rzymowski*, *Member, IEEE,* K. Nyka, *Member, IEEE,* and L. Kulas, *Senior Member, IEEE*
Department of Microwave and Antenna Engineering
Faculty of Electronics, Telecommunications and Informatics, Gdansk University of Technology
Gdansk, Poland
mateusz.czelen@pg.edu.pl, mateusz.rzymowski@pg.edu.pl, krzysztof.nyka@pg.edu.pl, lukasz.kulas@pg.edu.pl

***Abstract*—In this paper, the influence of dielectric overlay size on miniaturized ESPAR antenna performance has been investigated. The dielectric overlay's main function is antenna's size reduction but it can also be used to modify its radiation pattern. This creates the possibility of easy adopting antenna parameters to different applications by swapping used overlay. In particular, the lowering of antenna's main beam elevation direction has been considered. By using selected alternative overlay one can obtain a 20° lower beam. The design was confirmed by realization and measurements.**

***Keywords*—reconfigurable antenna, antenna miniaturization, 3D printing, electronically steerable parasitic array radiator (ESPAR) antenna**

I. Introduction

Electrically steerable passive array radiator (ESPAR) antennas are a low-cost and energy-efficient solution allowing implementation of beam steering capability in wireless communication and sensing systems [1]. Typical construction consists of a single active element and a number of passive ones surrounding it. Controlling passive elements' load impedance allows one to modify antenna radiation pattern [2]. In the introduced antenna designs, variable loads are realized with pin diodes, varactors or RF switches. The last option simplifies the steering circuit, so that it can be relatively easily integrated with a compact and inexpensive wireless sensor network (WSN) node [3]. This results in improved performance of the whole network in terms of energy-efficiency, connectivity and coverage [4]. In wireless systems, an important antenna property is its size. For that reason ESPAR antenna was miniaturized, which has been achieved by embedding all radiators in dielectric overlay [5]. The similar effect at lower cost can be reached utilizing 3D print technology and common polylactic acid (PLA) filament [6]. Industrial operation environment forces increased wireless systems requirements which can differ depending on particular application. In the scenario where ESPAR antenna is mounted on a ceiling, the network nodes' placement heights imply different desired radiation patterns. If nodes are spread across 3D space, desirable would be a pattern uniform in the elevation plane and when all nodes are on the approximately same level, optimal would be aligning the main beam to the horizontal plane. Lowering the elevation direction of the maximum radiation can be achieved by introducing a conductive sleeve connected to the edge of the antenna ground plane [7]. In this paper, we investigate the possibility of obtaining a similar effect by modifying the dimensions of the dielectric overlay that is originally intended for the antenna's miniaturization.

Research leading to these results has received funding from the EU ECSEL Joint Undertaking under grant agreement n° 826452 (project Arrowhead Tools) and from the partners national funding authorities the National Centre for Research and Development on behalf of on behalf of the Ministry of Science and Higher Education in Poland.

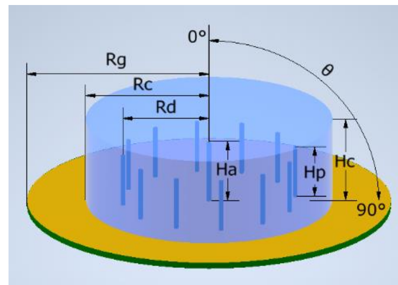

Fig. 1. Miniaturized ESPAR antenna structure

II. Antenna Structure

The proposed antenna structure is presented in Fig. 1 and consists of 13 monopole elements mounted on a circular ground plane. Only the central one is excited while the rest of them are terminated with electronically steerable loads. In the proposed design, passive element acts as a reflector when it is loaded by a short circuit and as a director when it is open-circuited. The configuration of five consecutive directors and seven reflectors results in a directional radiation pattern. The position of the middle opened element determines the horizontal direction of the main beam. The load control circuits are based on SPDT switches and provide a simple way to steer the antenna's beam. All radiating elements are embedded in a cylindrical dielectric overlay in order to reduce antenna's size. The material utilized for that purpose is inexpensive and commonly used in 3D print technology PLA filament. A detailed antenna design is described in [6], where the optimized dimensions in millimeters are: $R_g = 59.0$, $R_d = 28.2$, $H_a = 20.4$, $H_p = 16.8$, $R_c = 32.6$ and $H_c = 24.4$. This model of the antenna was used as a starting point for further experiments.

III. Modification of the Overlay Size

In order to investigate the influence of overlay dimensions on the antenna performance, cylinder height H_c and radius R_c

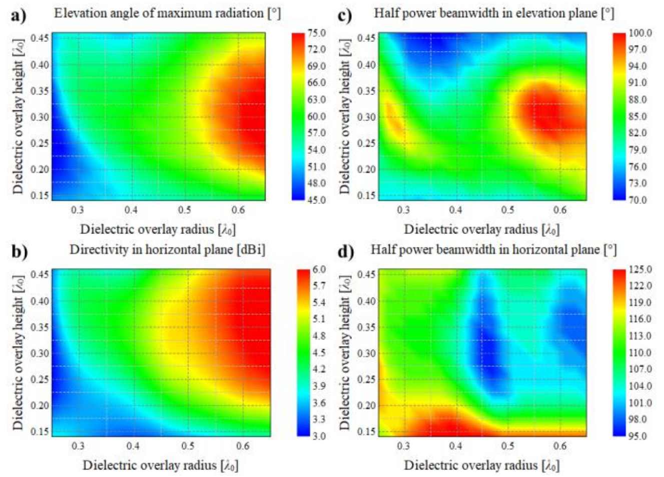

Fig. 2. Antenna parameters at 2.45 GHz in the function of dielectric overlay dimensions: a) elevation angle of maximum radiation [°], b) directivity in horizontal plane [dBi], c) HPBW in elevation plane [°], d) HPBW in horizontal plane [°]

were swept and number of antenna parameters were calculated for each sweep point defined as (R_c/λ_0, H_c/λ_0). The sweep ranges for free space wavelength λ_0 at 2.45 GHz were set to (0.20 … 0.65, 0.14 … 0.46), while the step size was $0.02\lambda_0$ (≈ 2.4 mm). The remaining dimensions were left unchanged. Numerical results in terms of elevation angle of maximum radiation, horizontal plane directivity and half-power beamwidth (HPBW) are presented in Fig. 2. By analyzing above characteristics one can notice that increasing R_c, while H_c is in the range from 0.25 to 0.4, causes an increase of the antenna elevation angle and horizontal directivity. Additionally, this effect is followed by horizontal narrowing in and broadening in elevation plane of the antenna's main beam. The initial design's main optimization goal was side lobe level reduction but in this case, particularly interesting is increasing main beam elevation angle which reaches its maximum near the sweep point (0.65, 0.3).

IV. Realized Antennas

An additional antenna version focused on increasing the main beam elevation angle θ has been fabricated and measured. The alternative overlay dimensions were also determined by the antenna's ground plane radius in order to maintain antenna's base radius reduction factor unchanged while providing satisfactory impedance matching. In the result, values of $H_c = 0.25\lambda_0$ (≈ 30 mm) and $R_c = R_g = 0.48\lambda_0$ (≈ 59 mm) have been chosen. Such configuration resulted in a main beam elevation angle increase from 46° to 66° (Fig. 4a). The overlay was fabricated with RAISE3D Pro2 Plus printer using exactly the same settings as the smaller version. Fig. 3 shows both fabricated antenna versions. Simulation and measurements results are in good agreement in terms of radiation pattern and reflection coefficient (Fig. 4).

V. Conclusions

The antenna radiation pattern can be significantly modified only by adjusting the dielectric overlay dimensions. In this paper, we investigated this effect in terms of such parameters as main beam elevation angle and HPBW. Numerical simulations

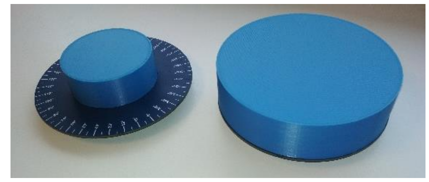

Fig. 3. Two versions of realized antanna

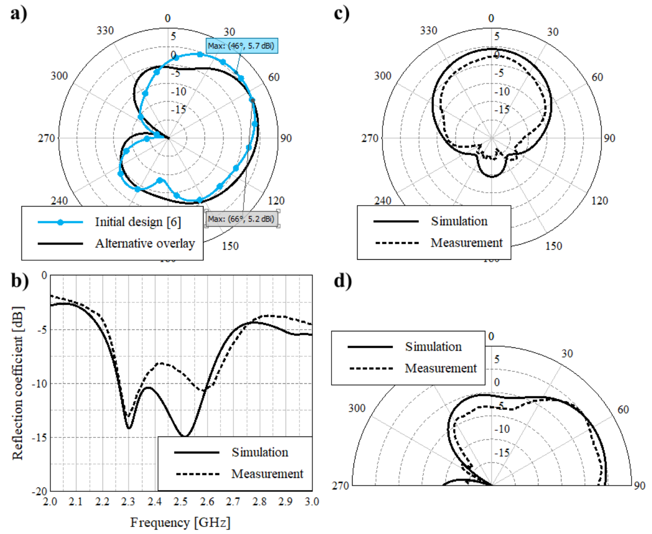

Fig. 4. Simulation and measuremen results of including alternative overlay: a) elevation radiation pattern comparision with inital design at 2.45 GHz [dBi], b) reflection coefficient [dB], c) radiation pattern in horizontal plane at 2.45 GHz [dBi], d) radiation pattern in elevation plane at 2.45 GHz [dBi]

have been confirmed by fabrication and measurements of the antenna with alternative overlay. An increase of the elevation angle of the antenna's main beam has been achieved. What is an important advantage of this approach, the main structure of the antenna needs to be manufactured just once and its characteristic can be adapted to particular application by adding a suitable overlay. The utilization of 3D print technology and common PLA filament makes this modification inexpensive and fast.

References

[1] H. Kawakami and T. Ohira, "Electrically steerable passive array radiator (ESPAR) antennas," *IEEE Antennas Propag. Mag.*, vol. 47, no. 2, pp. 43-50, April 2005.

[2] E. Taillefer, A. Hirata, and T. Ohira, "Direction-of-arrival estimation using radiation power pattern with an ESPAR antenna," *IEEE Trans. Antennas Propag.*, vol. 53, no. 2, pp. 678–684, Feb. 2005.

[3] M. Rzymowski, P. Woznica and L. Kulas, "Single-anchor indoor localization using ESPAR antenna," *IEEE Antennas Wireless Propag. Lett.*, vol. 15, pp. 1183-1186, 2016.

[4] F. Viani, L. Lizzi, M. Donelli, D. Pregnolato, G. Oliveri, and A. Massa, "Exploitation of parasitic smart antennas in wireless sensor networks," *J. Electromagn. Waves Appl.*, vol. 24, no. 7, pp. 993-1003, Jan. 2010.

[5] Junwei Lu, D. Ireland and R. Schlub, "Dielectric embedded ESPAR (DE-ESPAR) antenna array for wireless communications," *IEEE Trans. Antennas Propag.*, vol. 53, no. 8, pp. 2437-2443, Aug. 2005.

[6] M. Czelen, M. Rzymowski, K. Nyka and L. Kulas, "Miniaturization of ESPAR antenna using low-cost 3D printing process," in press

[7] Y. Ojiro, H. Kawakami, K. Gyoda, T. Ohira, "Improvement of elevation directivity for ESPAR antennas with finite ground plane", *Proc. IEEE Int. Symp. Antennas Propag.*, vol. 4, pp. 18-21, Jul. 2001