Proc. 29th National Conference with International Participation "Telecom 2021", October 28 - 29, 2021, Sofia, Bulgaria

Z-shape EBG Structure Improving the Phased Antenna Array Radiation Pattern with Autonomous Aerial Vehicle Navigation Application

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***Abstract* — The paper discusses a Z-shape electromagnetic band gap (EBG) structure to improve the radiation characteristic of various antenna types. Experimental results of EBG structures integration in the phased array antenna (2x2 construction variety and nine radiation pattern states) show that structures of this type, designed to meet the document described conditions, is available to improve antenna radiation characteristic – increases the antenna gain and narrow the radiation pattern beamwidth. The study purpose is to show that when integrating the structure into the scanning antenna array, offset angle of the antenna beams in the scanning mode also changes. In addition, increasing gain and narrowing the beamwidth also can reduce side lobes levelsA comparison between simulated and measured results of the antenna system is presented, which clearly shows the improving properties of the proposed structure.**

Keywords—Electronic Band-Gap (EBG) structures, periodic structure, metamaterial, beamforming, antenna gain, radiation pattern, UAV, automatic landing

I. INTRODUCTION

Applications of unmanned aerial vehicles (UAV) for various purposes have grown dramatically in recent years - in industry, research, and scientific environments [1÷5]. The UAV-wide application creates many case studies for optimization and improvements of various existing systems, such as: landing systems [7÷9], fast charge UAV batteries [11, 12], size reduction, and providing optimization of stability during flight [13, 14], and etc.

The present research focuses on optimizing methods for locating, tracking, and landing UAVs - using antennas and antenna arrays (AR) [15÷17]. These methods are relatively reliable when landing in conditions of poor visibility, hard-to-reach places, and landing on moving objects. For this purpose, constructing a landing pad (using antennas and antenna arrays for localization and control) must have dimensions commensurate with flying vehicle dimensions. A significant disadvantage of AR composed of few elements is high levels of radiation pattern (RP) side lobes and a limited offset RP angle in the scanning mode. Innovative band structures in antenna and microwave design – PBG [18] and EBG [19, 20] allow for improving the different types of antennas radiation parameters [21, 22]. This structure increases the antenna's gain, reduces RP beamwidth, and changes the antenna beam offset angle in scanning mode.

This paper discusses the antenna system, which consists of an implemented Z-shape EBG structure in a phased antenna array (PAA. The PAA has 9 antenna beam states in scan mode. An EBG structure is chosen over a photonic band gap (PBG) structure. Both structures have similar improving characteristics against antenna RP. However, from a topological point of view, the EBG structures is compact for integration into an already existing planar antenna. Implemented band gap structure supports the antenna RP and changes antenna beams offset scan. The investigation compares simulated and measured results of the synthesized antenna system, which clearly demonstrate the proposed structure improving properties. The antenna array with bettered radiation characteristics will increase the UAV control and localization system's dynamic range and show a specific application of the verified periodic structures in one radio localization system.

II. Z-SHAPE EBG STRUCTURE DESIGN

Z-shaped configuration was used for the electromagnetic band structure element, characteristics of which as a periodic structure are discussed in detail in [22]. After selecting the structure type, two Z shape EBG structures are designed. The structure frequency range is 2.4GHz - a frequency used by already existing UAV control systems - and also the phased antenna array work frequency in which the structures will be integrated. A peculiarity in the design of such a structure type is that in the design process, so-called dispersion analysis is used. Reflection and transmission coefficient in the frequency domain of a structure should be ≈-3dB on central frequency in order to improve the radiation parameters of a given antenna. Necessary requirements for frequency characteristics of structures of this type to enhance the antenna radiation characteristic are discussed in detail in [21, 22]. Based on the mentioned requirements, **EBG_Structura_1** and **EBG_Structura_2** were designed to be integrated into the PAA. Figures 1 and 2 show the manufactured **EBG_Structure_1** and **EBG_Structure_2**. Figures 3 and 4 show the characteristics of the fabricated structures obtained by dispersion analysis.

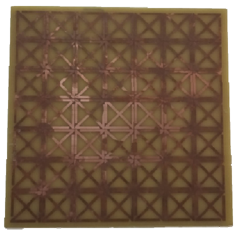

Fig.1. Crafted **EBG_Structure_1**

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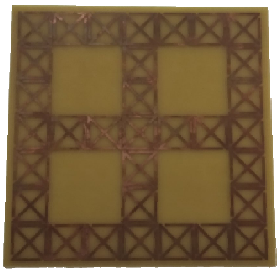

Fig.2. Crafted **EBG_Structure_2**

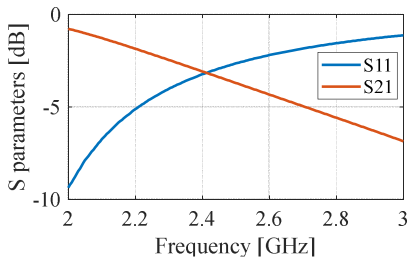

Fig.3. **EBG_Structure_1 S** parameters

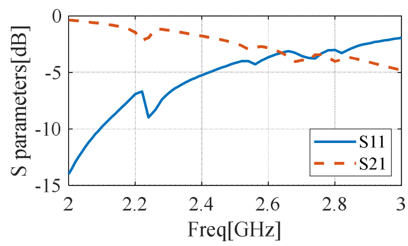

Fig.4. **EBG_Structure_2 S** parameters

The crafted structures are placed close to the antenna emitting surface (in this case, in the PAA surface front), as shown in Fig. 5, after which the optimal distances between structure and antenna (for central beam state) are sought - fig. 6 and 7. PAA [23] gain without structure is 7.5dBi.When finding the optimal distance, this is also the distance at which the structure is mounting.

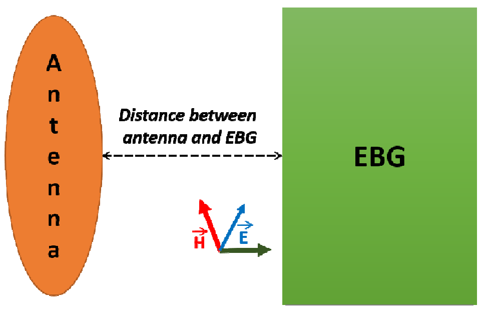

Fig.5. Placement of the EBG structure relative to the antenna

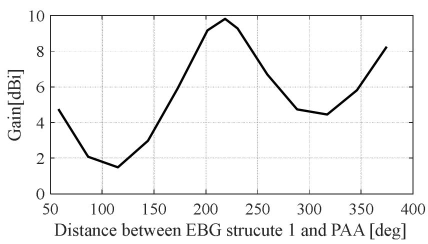

Fig.6. Gain vs distance between PAA and **EBG_Structure_1**

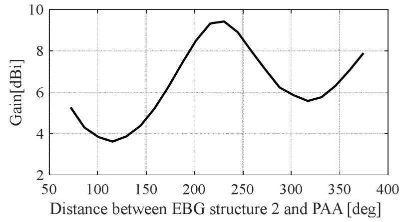

Fig.7. Gain vs distance between PAA and **EBG_Structure_2**

III. Results Of The Improvement Radiation Pattern By Implementing The Z-Shape EBG Atructure In The Phased Antenna Array

In the preceding point, it can be seen that the two designed structures have similar frequency characteristics. Figures 6 and 7 show analogous e antenna gain increase. A previous study of this type of structure presented in [22] shows that they also have a similar narrowing in the RP beamwidth. **EBG_Structure_1** is implemented in PAA - figure 9. Figures 10 ÷ 14 show a comparison between simulation and measured results of antenna beam, measured using an autonomous antenna radiation measurement system [23]. Figures 15 ÷ 19 compare the measured radiation pattern of PAA with and without the selected EBG structure.

Fig.8. Using PAA

Fig.9. EBG via PAA implementation

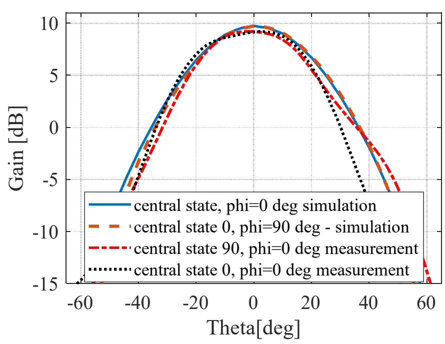

Fig.10. Central RP state, simulation vs measurement results

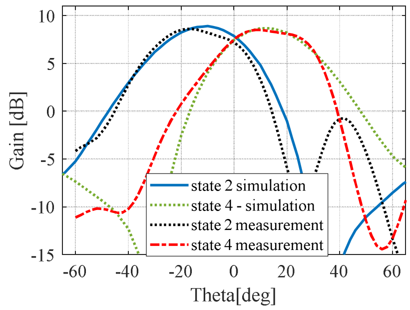

Fig.11. RP states 2 and 4, simulation vs measurement results

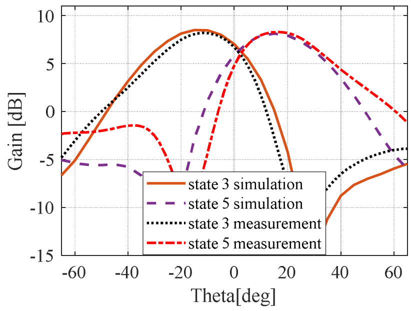

Fig.12. RP states 3 and 5, simulation vs measurement results

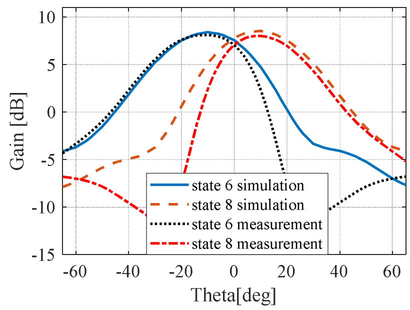

Fig.13. RP states 6 and 8, simulation vs measurement results

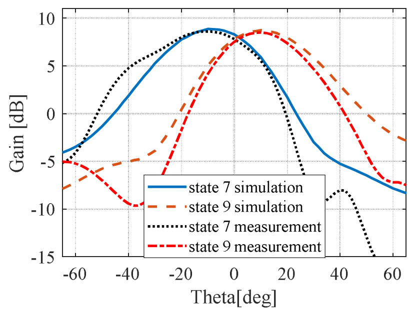

Fig.14. RP states 7 and 9, simulation vs measurement results

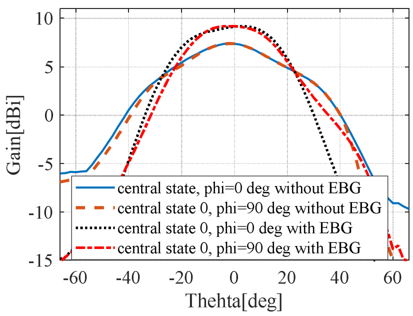

Fig.15. Comparison of Central RP state with and without the proposed **EBG_Structure_1**

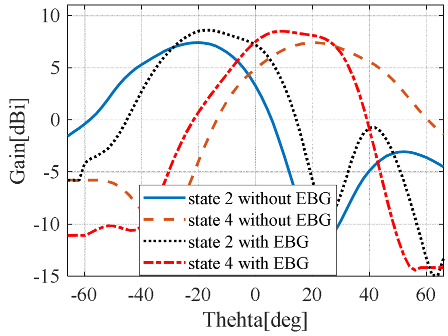

Fig.16. Comparison of 2 and 4 states with and without the proposed **EBG_Structure_1**

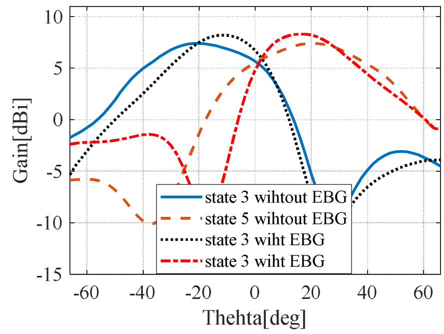

Fig.17. Comparison of 3 and 5 states with and without the proposed **EBG_Structure_1**

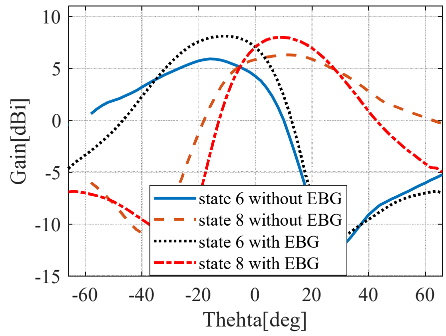

Fig.18. Comparison of 6 and 8 states with and without the proposed **EBG_Structure_1**

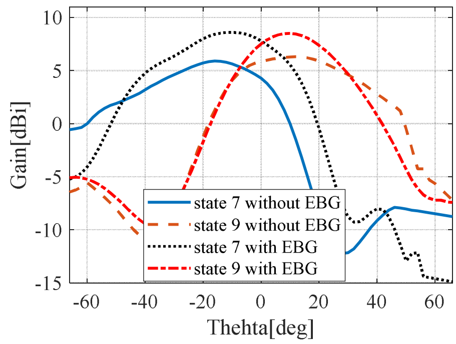

Fig.19. Comparison of 7 and 9 states with and without the proposed **EBG_Structure_1**

Therefore, from the comparison between simulated and measured results, the electromagnetic band gap structure has suitable parameters to improve the antenna array beam in which it is integrated. A significant shrinkage of the RP width sheets in the existing condition and an increase in the antenna gain are observed. Table 1 compares the measured

RP with and without band structure. It is seen that the use of the discussed type of structure changes the antenna beam offset angle in scanning mode, which is also a new contribution to antenna design from the paper.

TABLE I. COMPARISON BETWEEN PHASED ANTENNA ARRAY RADIATION PATTERNS WITHOUT AND WITH **EBG_STRUCTURE_1**

RP state	Gain without EBG [Dbi]	Gain with EBG [Dbi]	RP beam with-out EBG [deg]	RP beam -with with EBG [deg]	RP deviation from central state without EBG [deg]	RP deviation from central state with EBG [deg]
state 1	7.4	9.2	48º	37º	-	-
state 2	7.4	8.6	46º	40º	-20º	-16º
state 3	7.4	8.5	48º	39º	20º	14º
state 4	7.4	8.2	47º	34º	-20º	-12º
state 5	7.4	8.3	48º	35º	20º	16º
state 6	6	8.1	46º	34º	-16º	-10º
state 7	6.3	8	48º	34º	12º	8º
state 8	6	8.3	46º	38º	-16º	-10º
state 9	6.3	8.2	46º	36º	12º	8º

IV. CONCLUSION

The research shows that it is possible to realize an antenna system consisting of an EBG structure implemented in an antenna array with electronic scanning and 9 states of the scanning diagram. A gap structure of the considered type can be used in already existing antennas where an increase in gain is required, and the corresponding communication does not require a wide coverage area. It is important to note that the considered structure can be used not only to improve the radiation characteristic of an antenna array but also to change the angle of the antenna beam tilt from the central state to the scanning mode, confirmed by the new research shown in the article. The tests done are satisfactory and improve the dynamic range of the antenna.

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