Design of a Compact Circular Waveguide Antenna of Low Polarization Level using EBG Structures

Josefa Gómez, Abdelhamid Tayebi, Iván González, and Felipe Cátedra

Computer Sciences Department
University of Alcalá, 28871 Alcalá de Henares (Madrid), Spain
josefa.gomezp@uah.es, hamid.tayebi@uah.es, ivan.gonzalez@uah.es, felipe.catedra@uah.es

Abstract **─** A new technique to improve the performance, in terms of bandwidth, gain and polarization purity, of conventional circular waveguide antennas using an electromagnetic band gap (EBG) structure is presented. The proposed antenna is composed by a circular waveguide and two layers with squared holes located over the waveguide aperture. The dimensions of the antenna have been obtained by means of an optimization process that uses a rigorous analysis tool. According to the results, a notable enhancement in polarization purity and gain is demonstrated when incorporating the second grid. The EBG antenna has the peak gain 14.36 dBi and the cross polarization level is lower than 40 dB within a wide bandwidth of 17%. A prototype has been fabricated and measured operating at 9.1GHz.

Index Terms **─** Antenna measurements, antenna radiation patterns, method of moments (MoM), waveguide antennas.

I. INTRODUCTION

It is well known that electromagnetic band gap (EBG) materials are designed to impede the propagation of electromagnetic waves at certain frequency bands that are determined by the periodicities of the materials and their dielectric constants. Recently, various applications of EBG materials, such as microwave filters, antennas, amplifiers, microstrip devices, ground plane structures, and base station antennas have been reported in the literature [1-4]. For example, EBG material has been shown to enhance the directivity of a patch antenna from 8 dB to 20 dB [1]. Palikaras *et al.* [2] described a method to design directive antennas by incorporating cylindrical EBG structures. On the other hand, [3] presents a resonator antenna that increases its gain and bandwidth with an EBG structure over the device. It has also been demonstrated [4] that the EBG materials are able to provide good results while reducing the size of some kind of filters.

The work presented in [5] summarizes the benefits of using EBG materials to improve the performance of microwave and optical applications. Some experimental results are discussed to check the properties of these materials.

According to [6], an increase in directivity can be obtained by adding a partially reflecting sheet in front of the antenna because of the multiple reflections between the sheet and the screen. The resonance distance between both elements must be such that the rays projected through the sheet have equal phases in the normal direction. Our contribution is focused on that investigation line. However, a deeper study is done here: we analyze the inclusion of a second grid over the antenna aperture and its influence over the cross polarization level. Numerical results demonstrate an improvement in gain, bandwidth and polarization purity when comparing several antenna configurations varying the distances between both grids.

The aim of this paper is to design a compact EBG antenna that provides a gain greater than 14.0 dBi, polarization purity greater than 40 dB, and a bandwidth greater than 10% while maintaining a very small size. To fulfill these requirements, the dimensions of the antenna were optimized by using a powerful electromagnetic solver. After obtaining the optimum dimensions, a prototype made of aluminum was built and measured.

II. GEOMETRICAL MODEL

The proposed antenna configuration is depicted in Fig. 1 where the dimensions are in meters. The antenna model is defined by a long metallic cylinder with a 13.9 mm radius, a short metallic cylinder with a 16.9 mm radius, and 12.5 mm length, an 80 x 80 mm ground plane and the EBG structure (also 80 x 80 mm). According to Fig. 1.b, an electric dipole located at λ/4 from the bottom of the circular waveguide has been used to model the feeding of the waveguide in the simulations. The dipole is oriented in the *x* axis parallel to the bottom of the waveguide.

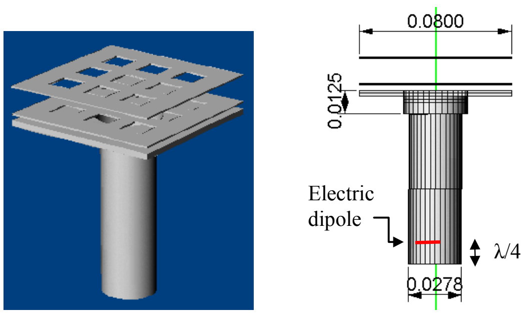

Fig. 1. Schematic representation of the proposed antenna, 3-D (left) and side view (right).

Each grid is composed of a metallic sheet with nine square holes. Figure 2 shows the dimensions (in meters).

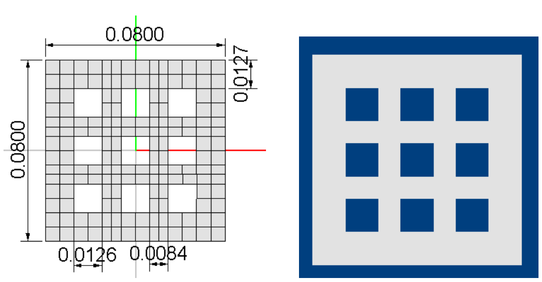

Fig. 2. Physical dimensions (in meters) of the EBG structure.

The distance between the ground plane and the first metallic grid was established to prevent cavity resonances at the operating frequency whereas the distance between the two metallic grids was set to obtain the classical EBG mode that permits an efficient antenna performance.

A parametric analysis was conducted to find the dimensions shown in Fig. 2. The first step in the design process was choosing the unit cell shape of the periodic structure. Some candidates were studied, such as rectangles, triangles, circles, rhombs, and crosses. After an exhaustive study, the square hole was chosen because of its simplicity and its good response. The next point was the optimization of the structure dimensions a central frequency of 9.1 GHz. Several geometrical parameters (the distance between adjacent holes, the size of the holes, the number of holes, etc.) were optimized. After the analysis of the position of the periodic structures, we conclude that the upper grid must be located 17.5 mm from the ground plane and the lower grid must be situated 3.5 mm from the ground plane. Those are the optimum physical dimensions to achieve the desirable radiation characteristics of high gain and low cross polarization level. The remaining geometrical parameters related to the waveguide were fixed.

The design was implemented using Monurbs [7], a versatile electromagnetic solver based on the moment method that uses parametric surfaces for representing the geometrical model and the current of the structures under analysis. Monurbs has been validated with real measurements in many applications. The optimization process was carried out using a new module of the tool that allows us to set the requirements and the geometrical parameters to vary. The simulation process finishes when the optimization module finds the optimum parameter values that provide the desired radiation pattern. As mentioned before, in this case the cost function was defined to obtain high polarization purity and high gain over a wide bandwidth. The values of the geometrical parameters must be assigned within a certain range defined by the user. The minimum and maximum values for the size of the squared holes were 8mm and 14mm, respectively. Regarding the resonance distances between the grids, the height of the lower grid from the ground plane was optimized within the range from 3mm to 7.5mm and the height of the upper grid from the ground plane was optimized within the range from 9 and 18mm.

III. RESULTS

To validate the simulation results, a prototype of the designed EBG antenna was built based on the optimized antenna geometry. The prototype was measured in an anechoic chamber. Figure 3 depicts a photograph of the built antenna.

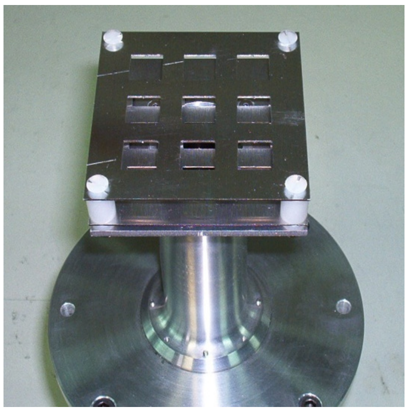

Fig. 3. Prototype of the EBG antenna.

The antenna was made of aluminum and weighed nearly 400 g. The pair of metallic grids was kept fixed by four plastic screws. The screws crossed the ground plane and kept the three different parts together. The antenna was fed to radiate linear polarization.

Figures 4 through 7 show comparisons between the measurements and the simulated values for the three main radiation cuts at 9.1 GHz.

The proposed antenna provides the maximum radiation in the axial direction. Good agreement between real measurements and computations was shown. The slight discrepancies between measurements and simulation values may be due to unwanted effects as well as non-idealities introduced by the four screws and the manufacturing errors. Also, the cross polarization level in the E and H plane cuts is below -40dB.

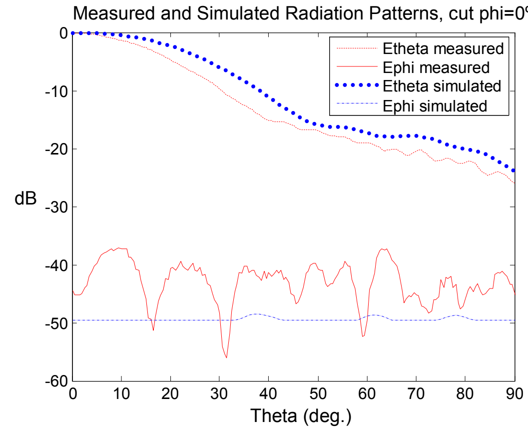

Fig. 4. Comparison of the simulated and measured radiation patterns. E-plane cut at 9.1GHz.

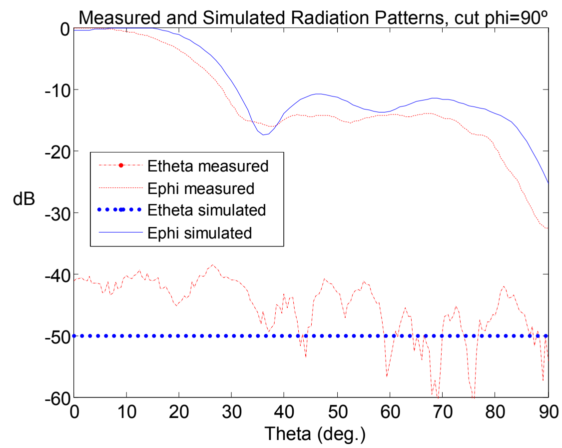

Fig. 5. Comparison of the simulated and measured radiation patterns. H-plane cut at 9.1 GHz.

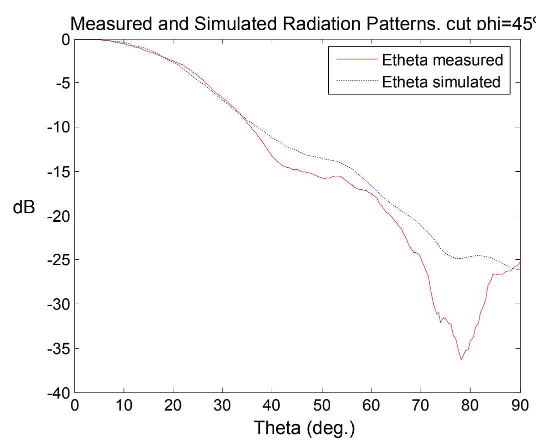

Fig. 6. Comparison of the simulated and measured radiation patterns. Diagonal-plane cut at 9.1GHz. Etheta component.

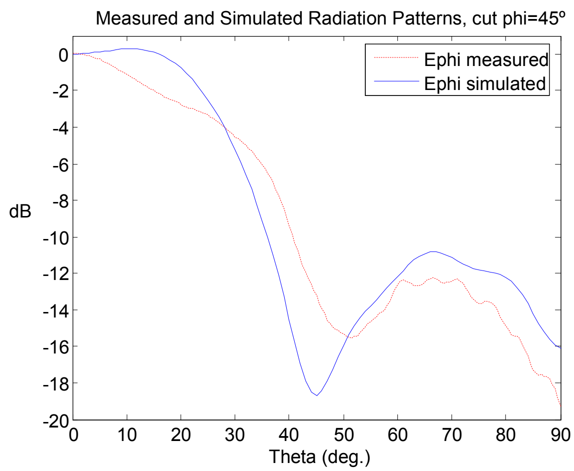

Fig. 7. Comparison of the simulated and measured radiation patterns. Diagonal-plane cut at 9.1GHz. Ephi component.

To verify the behavior of the EBG structure, several simulations were made to compare the results when the height of the cases were studied fixing the upper grid position at 17.5mm and changing the lower grid position at h1=4.3mm, h2=5.1mm, h3=5.9mm, h4=6.7mm, and h5=7.5mm. A decrease in gain was proven when the height of the lower grid increases, that is to say, when both grids are closer. This comparison ensures that the effect of including the second EBG structure is an enhancement in the gain lower grid changes or when there is only one grid.

The gain variation versus frequency is plotted in Fig. 8. Notice that a significant enhancement in gain is produced when including the second grid. It can be observed that the peak gain is located at 8 GHz when there is only one grid situated at 17.5mm from the ground plane. The maximum gain for the best configuration with two grids is 14.36 dBi at 9.0 GHz and the enhanced bandwidth (where gain did not decrease more than 3 dB below the maximum value) extends from 8.2 to 9.7 GHz, which means about a bandwidth of 17%.

On the other hand, a second comparison is shown in Figs. 9-10 to analyze the effect of moving the lower. Five different cases were studied fixing the upper grid position at 17.5mm and changing the lower grid position at h1=4.3mm, h2=5.1mm, h3=5.9mm, h4=6.7mm, and h5=7.5mm. A decrease in gain was proven when the height of the lower grid increases, that is to say, when both grids are closer.

This comparison ensures that the effect of including the second EBG structure is an enhancement in the gain at the central frequency.

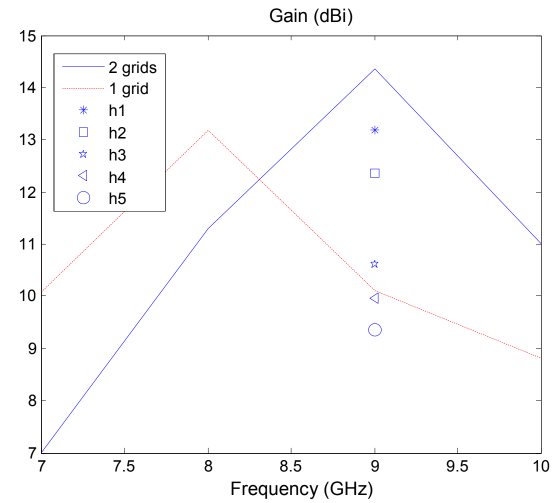

Fig. 8. Gain versus frequency. Comparison between results obtained considering only one grid (red line) and two grids located at optimum distances (blue line). The gain for several values of the height of the lower grid for the case of two grids is also shown for a frequency of 9.0 GHz.

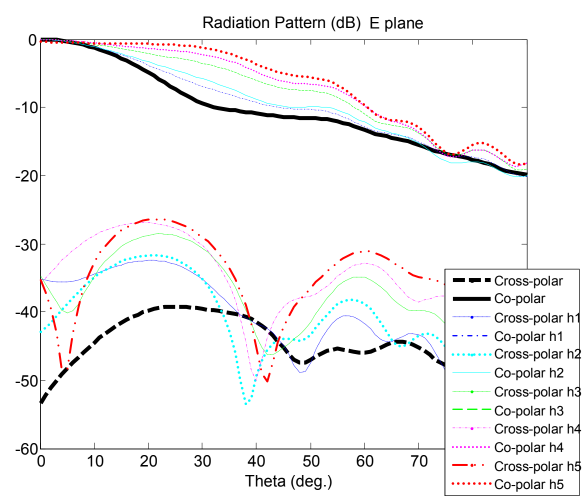

Fig. 9. Comparison between the simulated E-plane cuts at 9.0 GHz for several values of the height of the lower grid. The results for the optimum configuration are depicted in thick lines.

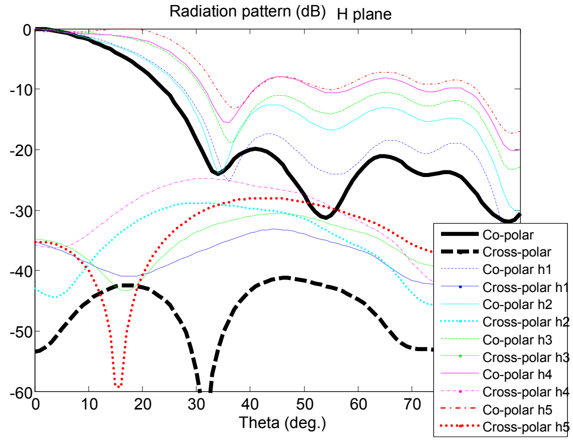

Fig. 10. Comparison between the simulated H-plane cuts at 9.0 GHz for several values of the height of the lower grid. The results for the optimum configuration are depicted in thick lines.

Table 1 summarizes the results of gain and cross polarization level at 9.0 GHz considering several EBG structures. The best configuration is obtained when the second grid is located at 3.5mm from the ground plane. The gain for that case is 14.36dBi and the cross polarization level is 53.38dB. It is worth to highlight that the other configurations provide worse results.

Figs. 9 and 10 present the radiation patterns obtained for the six situations. The optimum configuration is shown in black color. The benefit of including the two EBG structures over the polarization purity can be observed in both E and H plane cuts.

Table 1: Gain and cross polarization level comparison when varying the height of the lower grid at 9GHz

Height of upper grid	**Height of lower grid**	**Gain (dBi)**	**CP-XP (dB) θ=0º, φ=0º**
17.5mm	3.5mm	14.36	53.38
17.5mm	h1 = 4 .3mm	13.19	35.12
17.5mm	h2 = 5.1mm	12.35	42.94
17.5mm	h3 = 5.9mm	10.61	34.8
17.5mm	h4 = 6.7mm	9.96	35.81
17.5mm	h5 = 7.5mm	9.35	34.9

We compare the radiation pattern of the antenna with and without the grids in Figs. 11 and 12. A significant enhancement in polarization purity can be appreciated. The improvement of the horn gain employing the EBG structure relative to the simple horn is shown in Figs. 13-15 for the three main cuts. Finally, return losses have been also computed and measured considering the antenna with and without grids. Figures 16-17 depict the results.

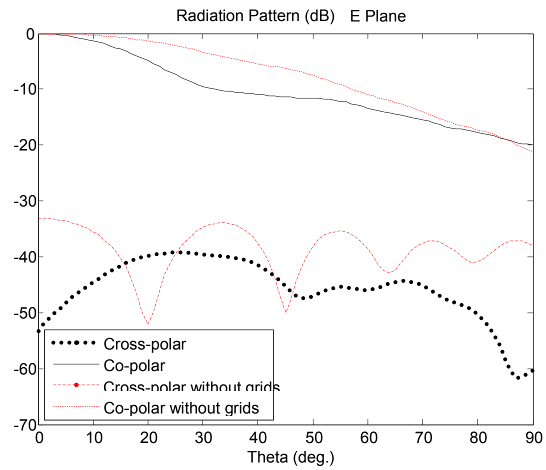

Fig. 11. Comparison between the simulated radiation patterns with and without grids. E-plane cut at 9.0 GHz.

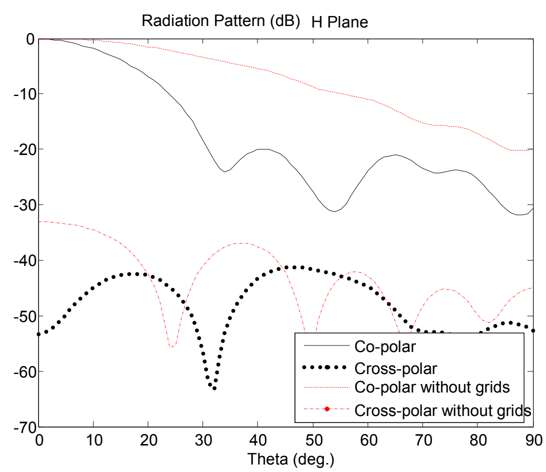

Fig. 12. Comparison between the simulated radiation patterns with and without grids. H-plane cut at 9.0 GHz.

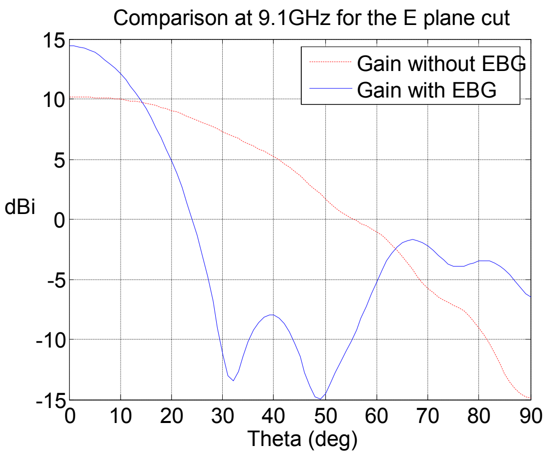

Fig. 13. Comparison for the antenna gain in the E-plane cut with and without grids.

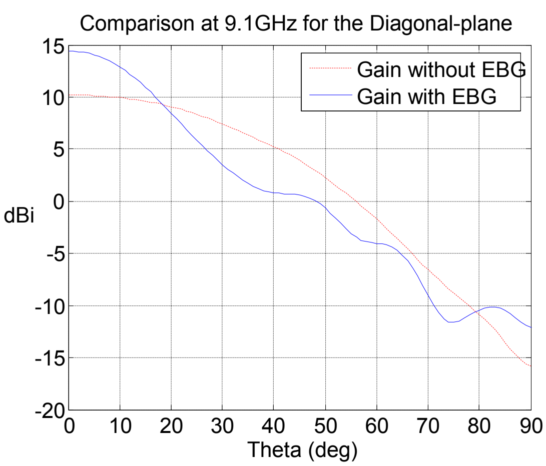

Fig. 14. Comparison for the antenna gain in the diagonal-plane cut with and without grids.

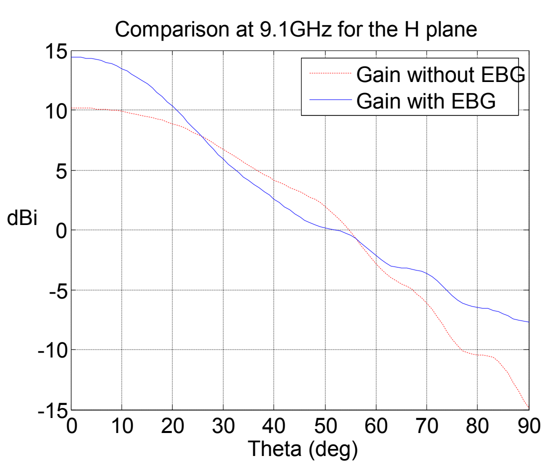

Fig. 15. Comparison for the antenna gain in the H-plane cut with and without grids.

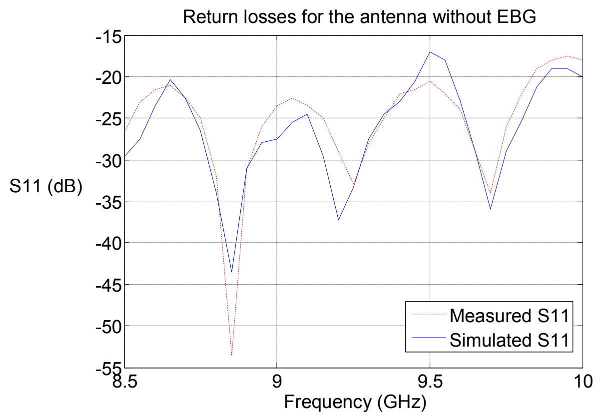

Fig. 16. Comparison of the return losses for the antenna without EBG.

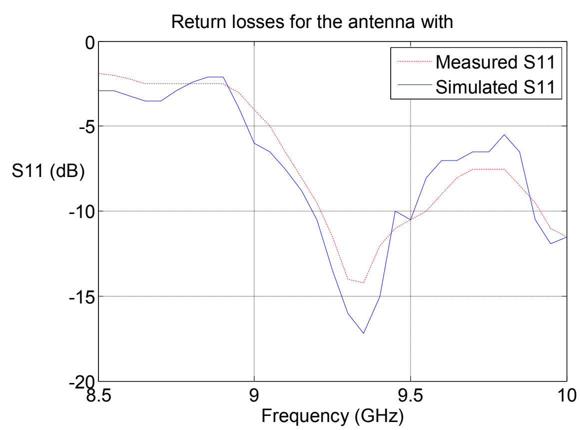

Fig. 17. Comparison of the return losses for the antenna with EBG.

IV. CONCLUSIONS

A novel compact EBG antenna operating at 9.1GHz has been presented. This new EBG antenna is an excellent candidate for several applications due to its good polarization purity. One of these applications is the design of compact antennas of medium or moderate gain and good polarization purity. Although a common horn antenna with an aperture surface equal to the proposed EGB antenna presents better performances in terms of directivity and polarization purity, the horn requires a length two or three times greater due to the large taper section it needs to fit the waveguide cross section to its final aperture surface. A second application is the design of arrays using the proposed antenna as a unit cell, as it is shown in Fig. 18. It is expected that the array will have good radiation characteristics for feeding multibeam reflector antennas which require a relative high gain for each array element. In this particular case, the usage of an array of horn antennas with similar gain is very difficult because of the collision between horns due to their large aperture size.

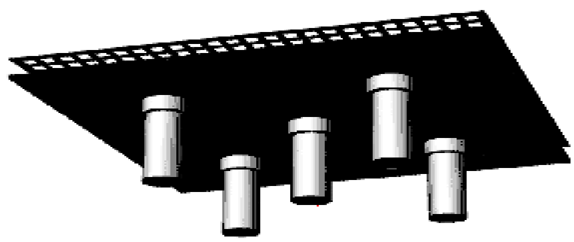

Fig. 18. Geometrical model of an array of antennas composed by five small waveguide antennas and an EBG structure that acts as a lens.

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Josefa Gómez Pérez was born in 1984. She received the B.S. and M.S. degrees in Telecommunications Engineering from the University Polytechnic of Cartagena (UPCT), Spain, in 2005 and 2007, respectively. Since 2007, she is pursuing the Ph.D. degree at the Computation Science Department, University of Alcalá, Spain. She has participated in several research projects with Spanish and European companies. She has published three papers and more than fifteen conference contributions at international symposia. Her research interests are design and optimization of antennas, electromagnetic radiation and scattering, on-board antennas analysis and design of graphical user interfaces.

Abdelhamid Tayebi Tayebi was born in 1983. He received the B.S. and M.S. degrees in Telecommunications Engineering from the University Polytechnic of Cartagena (UPCT), Spain, in 2005 and 2007, respectively. Since 2007, he currently is pursuing the Ph.D. degree at the Computation Science Department, University of Alcalá, Spain. He has participated in several research projects with Spanish and European companies. He has published three papers and more than fifteen conference contributions at international symposia. His research interests are design and optimization of antennas, electromagnetic radiation and scattering, on-board antennas analysis and design of graphical user interfaces.

Iván González Diego was born in Torrelavega, Spain in 1971. He received the B.S. and M.S. degrees in Telecommunications Engineering from the University of Cantabria, Spain, in 1994 and 1997, respectively, and the Ph.D. degree in Telecommunications Engineering from the Univeristy of Alcalá , Madrid, Spain in 2004. He worked in the Detectability Laboratory of the National Institute of Technical Aerospace (INTA), Madrid, Spain in RCS prediction and measurements and as Assistant Researcher at the University of Alcalá. Since 2004, he works as Assistant Professor in the University of Alcalá in the Computation Science Department teaching concepts about Data Base Systems. He has participated in several research projects with Spanish and European companies, related with analysis of on board antennas, radio propagation in mobile communications, RCS computation, etc. His research interests are in numerical methods applied to the electromagnetic problems, rigorous and asymptotic techniques like Method of Moments, GTD/UTD, PO, etc. Also, the numerical methods to represent complex bodies for the electromagnetic techniques and computer graphics is one of his research area.

Manuel F. Cátedra Pérez received his M.S. and Ph.D. degrees in Telecommunications Engineering from the Polytechnic University of Madrid (UPM) in 1977 and 1982, respectively. From 1976 to 1989, he was with the Radiocommunication and Signal Processing Department of the UPM. He has been Professor at the University of Cantabria from 1989 to 1998. He is currently Professor at the University of Alcalá, in Madrid, Spain. He has worked on about 90 research projects solving problems of Electromagnetic Compatibility in Radio and Telecommunication Equipment, Antennas, Microwave Components and Radar Cross Section and Mobile Communications. He has developed and applied CAD tools for radio-equipment systems such as Navy-ships, aircraft, helicopters, satellites, the main contractors being Spanish or European Institutions such as EADS, ALCATEL, CNES, ALENIA, ESA, DASA, SAAB, INTA, BAZAN, INDRA, the Spanish Defence Department.

He has directed about 18 Ph.D. dissertations, has published about 70 papers (IEEE, Electronic Letters, etc), three books, about 10 chapters in different books, has given short courses and has given around a hundred and thirty presentations in International Symposia.