Novel Woodpile Horn Antennas

I. Khromova[1], R. Gonzalo[1], I. Ederra[1], K. Esselle[2], B.P. de Hon[3]

[1]Department of Electrical and Electronic Engineering, Public University of Navarra
Campus Arrosadía, E31006, Pamplona, Navarra, Spain
Fax: + 34–948169720; email: irina.khromova@unavarra.es, ramon@unavarra.es, inigo.ederra@unavarra.es
[2] Department of Electronic Engineering, Macquarie University
email: karu.esselle@mq.edu.au
[2] Department of Electrical Engineering, Eindhoven University of Technology
P.O. Box 513, 5600 MB, Eindhoven, Holland
email: B.P.d.Hon@tue.nl

Abstract

Novel concept of feeding EBG horn antennas via evanescent fields is introduced. The principle of creating symmetrical all-dielectric pyramidal horn antennas based on woodpile structures is explained in detail. F band antennas based on the above mentioned concepts were designed, their Ku band scaled-up prototypes were fabricated and measured.

1. Introduction

In recent years electromagnetic band gap (EBG) structures [1,2] have been widely exploited for the purpose of shaping and improving the radiation characteristics of antennas of different types. In particular, EBG resonator cavities and defects [1-3] have been used to create antennas with large directivities and high efficiencies. Following the analogy with classical metallic horn antennas, introducing a horn-shaped hollow defect can make the EBG-based system work as a horn antenna [4-6].

This paper demonstrates a new concept of evanescent feeding for EBG horn antennas. It is shown that such horn antennas, realized as hollow defects in a three-dimensional (3D) periodic structure can be coupled to an EBG waveguide via evanescent fields existing in the embedding medium. This concept allows one to design compact arrays of EBG antennas, where horns can share feeds. A woodpile-based evanescently fed horn antenna operating in the F band (at around 110GHz) was designed and its scaled-up Ku band prototype was fabricated and measured.

EBG-based horn antennas in their present form despite offering a wide spectrum of applications still have several fundamental gaps and drawbacks. Up to now only sectoral horns embedded in one layer of rods in a woodpile structure have been designed. The reason for this is the lack of understanding of electromagnetic processes inside such structures. The other principal drawback of the woodpile horn antennas is the absence of mirror symmetry in the stacking direction of a woodpile structure, which results in non-symmetrical radiation patterns of the antennas. This work presents the design of a novel symmetric pyramidal horn antenna based on EBG structures. The main idea here lies in turning the EBG structure at the antenna flare angle and thus forming the EBG ”walls” of the horn. Basing on a careful modal analysis, this paper explains the fundamental difference between a gradual transition in metallic and EBG waveguides.

ISBN 978-952-67611-0-7

2. Evanescently fed EBG horn antennas

An EBG horn antenna can be realized as a hollow pyramidal-shaped defect of the ideal periodic structure. In a woodpile structure such a defect can be created by bending the dielectric rods (as proposed in [4,5]). This paper demonstrates that no direct coupling between the feeding EBG waveguide and the horn is needed. For instance, a double EBG horn antenna can be realized as shown in Fig.1, where the horn throats and the EBG waveguide end are separated by a slab of periodic structure.

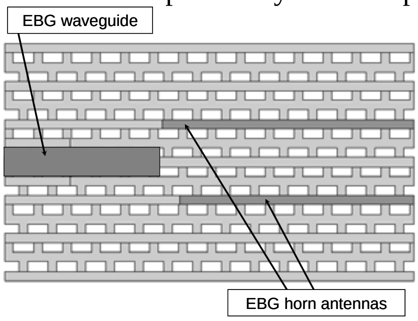
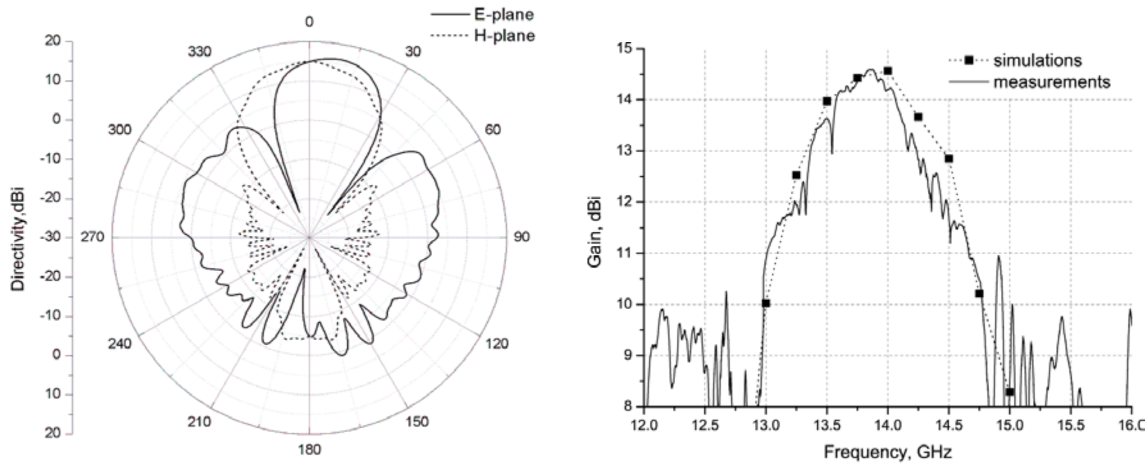


Fig. 1: Side-view of the evanescently fed double EBG horn antenna.

Unlike a typical device based on EBGs with defects, such a horn antenna is not a resonant structure and exhibits a large operation bandwidth. (approximately 11% for the design presented in this paper). The radiation pattern (Fig.2*a*) of such evanescently fed antenna arrays is improved in terms of directivity and beamwidth compared to single EBG horn antennas. However it is still not symmetric in the E-plane due to the absence of mirror symmetry in the stacking direction of the woodpile structure.
The double evanescently fed EBG horn antenna was fabricated and measured at Ku band (due to certain degree of scalability of EBG structures, such an experiment is valid as a demonstration of the concepts of evanescent feeding). Experimental results have shown a very good agreement with the numerical simulation data (Fig. 2*b*).



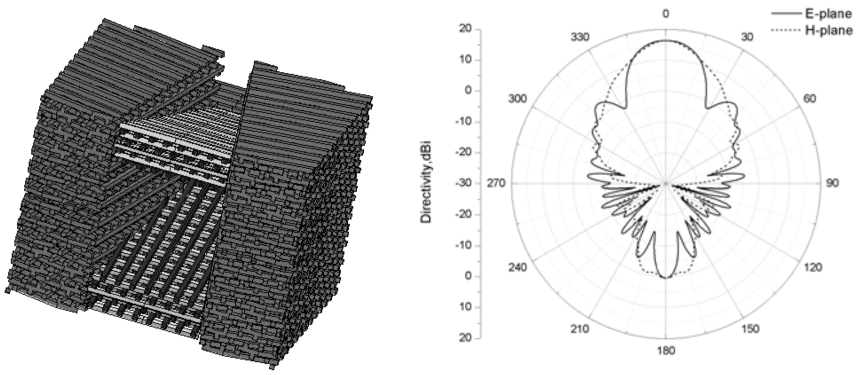
a *b*

Fig. 2: a) Double evanescently fed EBG horn antenna radiation pattern at 110GHz. b) Simulated and measured gain of the scaled-up Ku band prototype of the double evanescently fed EBG horn antenna.

3. Pyramidal horn antennas

As it was mentioned above, until now only sectoral horns realized within only one layer of the woodpile structure have been realized. It is not easy to create a woodpile pyramidal horn having an aperture in both E- and H-planes due to the complexity of this EBG structure, which does not permit a simple generalization of the "bent rods" idea for both E- and H-planes. Moreover, even a sectoral horn realized as a defect in several adjacent woodpile layers cannot be designed in a straightforward way. At the same time, such a solution would fit well for woodpile-based systems using more complex EBG

waveguides (for instance [7]). The absence of mirror symmetry in the stacking direction of the woodpile structure results in a fundamentally non-symmetric radiation pattern in the E-plane.
This paper proposes a solution to both of the above stated problems of the EBG horn antennas [8]. The adiabatic transition between the feeding EBG waveguide and the free space, provided by such antenna is possible thanks to the gradual shift of the periodic lattice nodes (Fig.4). The antenna presented in Fig.4 was designed for the F band, however it is also perfectly scalable and the same configuration can be used in different frequency ranges. Unlike its woodpile-based “predecessors”, this antenna possesses a symmetric radiation pattern in both E- and H-planes. Its directivity can be controlled by the changing the flare angle. This antenna operating at around 110GHz exhibits a more than 10% operating bandwidth and is significantly robust towards small errors in such parameters as flare angle and antenna throat position.



a *b*

Fig. 3: a) EBG pyramidal horn antenna. The woodpile sections are turned at the antenna flare angle. b) Radiation pattern of the EBG pyramidal horn antenna at 107GHz.

4. Conclusion

Two novel concepts concerning EBG horn antennas were introduced. The possibility of feeding of EBG horn antennas via evanescent fields was demonstrated both theoretically and experimentally. It is shown that a symmetrical pyramidal all-dielectric horn antenna can be created by stacking EBG slabs bent at certain angles. EBG antennas can substitute metallic horns in certain applications, which is especially valuable for microwave and THz devices.

5. Acknowledgements

This work was supported by the Spanish Ministry of Science and Innovation Project Nos. TEC2009-11995 and CSD2008-00066.

References

[1] R.D. Meade et al, Photonic bound states in periodic dielectric materials, *Phys Rev.B*, 44, 24, 13772-12774, 1991.
[2] S. Noda, A. Chutinan, and M. Imada, Trapping and emission of photons by a single defect in a photonic bandgap structure, *Nature*, 407, 6804, 608-610, 2000.
[3] I. Khromova et al, Resonance Frequency Behavior of 3D EBG Cavities, *J. Appl. Phys*,. 106, 014901-01498, 2009.
[4] R. L. Moore, M. P. Kesler, J. G. Maloney, and B. L. Shirley, US Patent 5,689,275, 1997.
[5]A. R. Weily, K. P. Esselle, B. C. Sanders, Layer-by-layer photonic crystal horn antenna , *Phys. Rev. E.*, 70, 037602-4, 2004.
[6] I. Khromova et al, Evanescently fed electromagnetic band gap horn antennas and arrays, submitted to *IEEE TAP*, 2010.
[7] I. Ederra et al. ,Electromagnetic Band Gap Waveguide for the Millimeter Range, *IEEE TMTT* , 58(7),. 1734-1741, 2010.
[8] I.Khromova et al, Symmetrical Pyramidal Horn Antennas Based on EBG Structures, *PIER B*, 29, 1-22, 2011.