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Miniaturization of printed antennas by using the EBG structures

#Moussa ELAYACHI [1], P. BRACHAT [1], Jean marc RIBERO [2]
[1] France Telecom R&D, 1581, Fort de tête de chien, 06320, La Turbie, France,
Tel : +33. (0)4.92.10.65.45. Fax : +33. (0)4.92.10.65.19
moussa.elayachi@orange-ftgroup.com,
[2] LEAT, UNSA, 250 rue Albert Einstein, Bât. 4, 06560 Valbonne, France,
Tel : +33. (0)4.92.94.28.42. Fax : +33. (0)4.92.94.28.12
Jean-Marc.RIBERO@unice.fr

1. Abstract

The aim of this study is to miniaturize a printed antenna by using Electromagnetic Band Gap (EBG) structures. In a first part, we describe the geometry and the electromagnetic characteristics of the printed antenna. We illustrate in the second part the solution suggested for this miniaturization. The procedure consists to design an EBG structure which works inside the band-width of the antenna, and employs this structure as reflector ground plane of the antenna. In the band gap of the structure, this plane behaves like an Artificial Magnetic Conductor. In the third part, we give the results of simulations and measurements obtained.

Key words – EBG structures, Artificiel Magnetic Conductor, printed antenna, Miniaturization of antennas.

2. Introduction

Since many years, the antennas are the object of many developments to allow their integration in communication terminals with more and more constraints on size reduction. Many techniques of antenna miniaturization exist. The usual methods include the use of substrates of high permittivity, plates with slits, or shorted-circuit plates. Each one is subjected to identified physical limitations and which often requires solutions compromised between band-width, size and efficiency of radiation.

Unlike the previous technique, a new method of miniaturization of the antennas consists to use the EBG structures which are able to synthesize artificial physical properties.

The EBG structures are periodic structures made of dielectric and/or metal materials designed to control the electromagnetic wave propagation. The absence of propagating modes in such structures, in a particular frequency band, is described as Band Gap. This band depends on the permittivity, size and form of the elementary cells composing the structure, the nature of texture, the periodicity, the angle of incidence and the polarization of incident electromagnetic wave [2].

We show in this article the thickness reduction of a printed antenna by using the EBG structure as ground plane reflector of this antenna.

2. Reference antenna description : Classic ground plane

The geometry of the reference antenna, on a classic ground plane, is illustrated on the fig.1. It consists of printed antenna which has a symmetry plane (oyz). Each symmetrical part is compound by an aerial element with two overlapping rhombuses. The antenna is printed on a dielectric substrate of permittivity $\varepsilon_r = 2.2$ and thickness h-sub = 0.75mm. An air-box is set below the substrate and of thickness h-air = 20mm which separates the antenna from the ground plane. This last has a size 180mmx180mm. The antenna is fed by coupling between the aerial element and a microstrip line witch is excited by a coaxial line. The total thickness of the reference antenna before miniaturization is h-tot = 20.75mm. The results of simulations and measurements of the

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return losses S11 and the radiation pattern, in both planes E and H, at frequencies 2.0GHz and 2.4GHz, are given on the fig.1. We note that the simulations were evaluated by HFSS code.

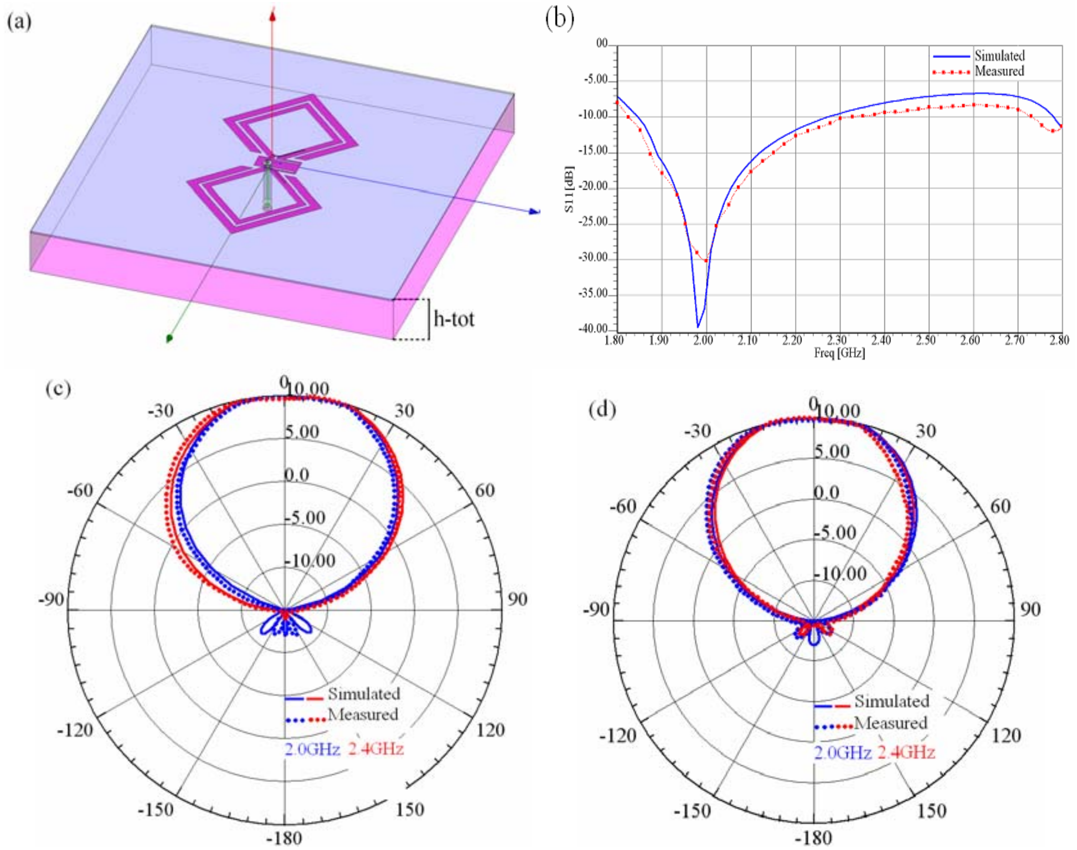

Fig.1: (a) Reference antenna on classic ground plane with h-tot = 20,75mm. (b) Return losses S11. (c) Radiation pattern in E-plane. (d) Radiation pattern in H-plane.

The reference antenna works inside the band of frequencies [1.85GHz - 2.25GHz]. Besides its perfect symmetry, this antenna is characterized by a high directivity and a high gain: Maximum gain is 10dB. 3dB Beam-width is about 60°. The main disadvantage, of this antenna, is a quarter wavelength thickness : h-tot = 20,75mm.

3. EBG structure design : Novel ground plane

To reduce the thickness of this antenna, we propose to design an EBG structure working inside the band-width of the antenna, and to use this structure as reflector ground plane of the antenna.

According to the theory of EBG structures, the limited $\lambda/4$ distance between the aerial element and the classic reflector plane of an antenna can be largely reduced. In fact, in the band gap, the EBG structure behaves like a magnetic conductor; a surface with high impedance. This last, has two essential properties: On the one hand, it allows the suppression of surfaces waves. On the other hand, it ensures the currents images to be in phase with the physical currents of the aerial element of the antenna [1]. Thus, inserted as reflector ground plane of the antenna, EBG structure makes possible to set the aerial element very close to the ground plane.

EBG Structure designed in this study is a Mushroom-like [1]. Based on the Reflection Phase Method [3], the EBG structure is designed on a dielectric substrate of permittivity $\varepsilon_r = 9.8$ and thickness h-ebg = 3.175mm with the following optimal parameters : The size of elementary cell 12mmx12mm including a 11.58mmx11.58mm of patch. The metallic via connecting patch and ground plane has a 1.4mm diameter. The distance which separates two successive patchs g = 0.42mm.

On fig.2, we show the reflection phase diagram obtained for the designed EBG structure. According to the criterion $\varphi = 0°(\pm 90°)$ [1], this diagram presents a band gap [2.1GHz-2.5GHz].

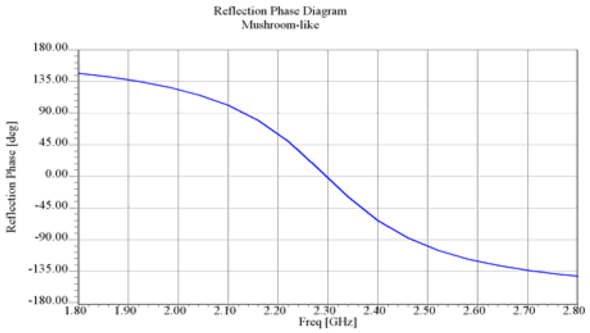

Fig.2: Reflection phase diagram.

4. Miniaturization of the reference antenna : EBG ground plane

Our objective is to insert the EBG structure as reflector ground plane of the antenna and to decrease the thickness of air-box at most possible while trying to preserve the initial performances of the reference antenna.

On the fig.3, we give the geometry of antenna on the new EBG ground plane. The air-box is decreased at the thickness h-air = 0.78mm. The total thickness of antenna after miniaturization becomes h-tot = 04.705mm. The results of simulations and measurements of the return losses S11 and the radiation pattern, in both planes E and H, at frequencies 2.0GHz and 2.4GHz, are illustrated on the fig.3.

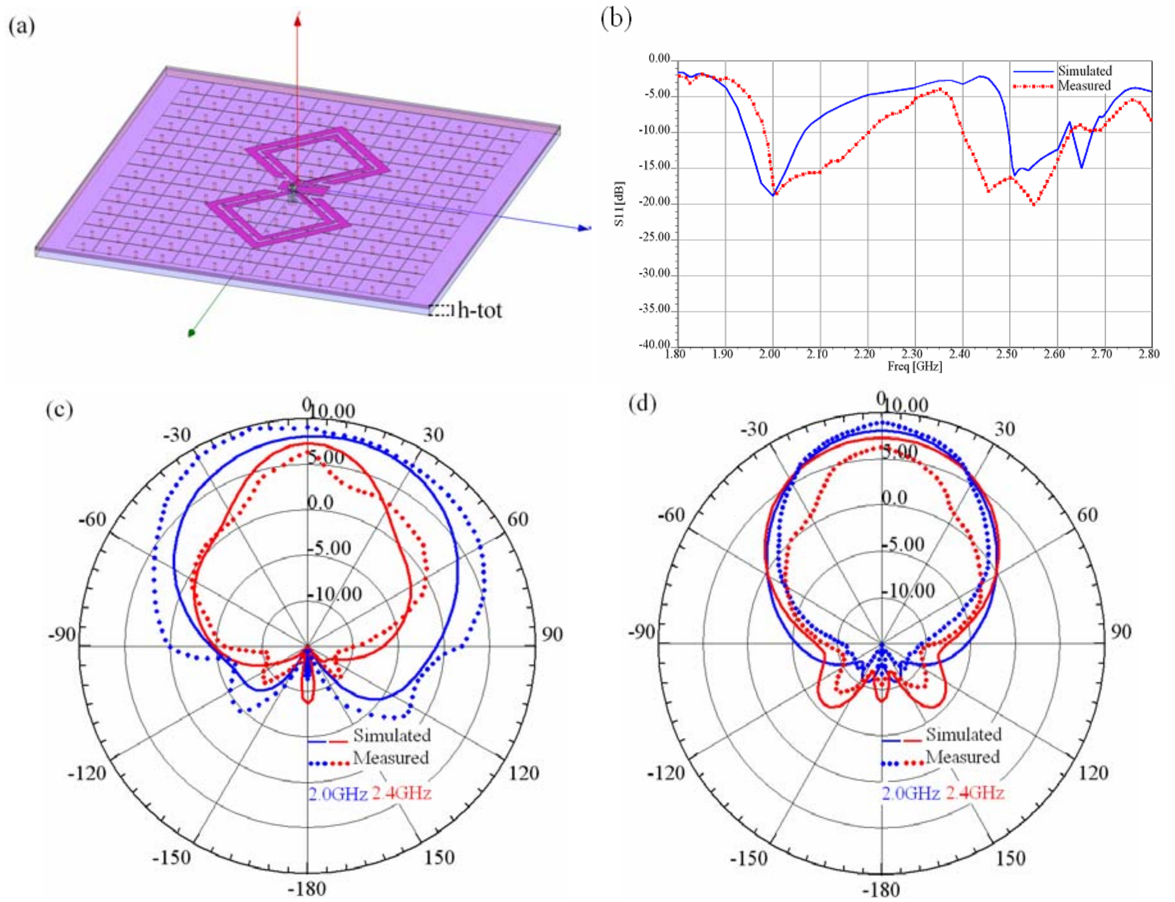

Fig.3: (a) Reference antenna on EBG ground plane with h-tot = 04,705mm. (b) Return losses S11. (c) Radiation pattern in E-plane. (d) Radiation pattern in H-plane.

By examining the obtained results and comparing with the initial performances of reference antenna, we have emphasized the following points :

● The measurement results confirm approximately the simulation results. We note, particularly, that the shape of the simulated S11 curve tends to converge to the curve obtained by measurements. This convergence is limited by the structure meshing which depends of performances of processors on which simulations were analysed.

● The antenna after miniaturization works on the two band-widths: [2.0GHz-2.2GHz] and [2.4GHz-2.7GHz]. The initial band-width was relatively preserved. Moreover, the EBG structure allowed the execution of a second band-width of the antenna.

● The radiation patterns are symmetrical in the two planes E and H. The insertion of the EBG structure preserved the symmetry of initial radiation pattern.

● In the H-plane, initial directivity is nearly preserved. Whereas, in the E-plane, the directivity of radiation pattern was relatively modified : Beam width was increased from 60° to about 90° at 2.0GHz, and decreased from 60° to about 30° at 2.4GHz.

● Also, we note the relative reduction, less than 3dB, in the maximum gain in both planes E and H, and apparition of a losses radiation in the backside of the antenna. This parasitic radiation is, probably, due to the electromagnetic coupling between the aerial element of the antenna and the patchs of EBG structure.

● Finally, the fact that the EBG structure introduced the apparition of a second band-width for the antenna may be a way to design Ultra Wide Band antennas by using the EBG structures.

In conclusion, except some slight modifications in gain ($7\text{dB} \leq \text{gain} \leq 10\text{dB}$), the obtained results show that by using the EBG structure as reflector ground plane of the antenna, we reduced the total initial thickness of antenna 20.75mm to 4.705mm; Consequently, an improvement of 77% of total thickness while preserving the initial performances of the antenna.

5. Conclusion

In this paper, we miniaturized a printed antenna by using the EBG structure. Using the method of reflection phase diagram, we designed an optimal EBG structure which presents the band gap : [2.1GHz-2.5GHz]. The designed EBG structure was inserted as a new ground plane and made possible to reduce the total thickness of antenna more than 77%, therefore obtaining a low profile antenna compared with the reference antenna. Moreover, the EBG structure have allowed the apparition of a second band-width of antenna; procedure which will be able to constitute a new way to design Ultra Wide Band antenna by using EBG structures.

6. References

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