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A New form of an Electromagnetic band-gap structure

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ABSTRACT: Generally speaking, the structure to forbidden electromagnetic band gap (EBG) is defined as being periodic artificial structures (or sometimes not periodic) which prevent the propagation of the electromagnetic waves in a frequency band specified for all the angles of incidence and all the states of polarization. The EBG is normally realized by periodic arrangement of dielectric materials. Within this framework, a new type of metallic electromagnetic structure was finalized. A big impedance of surface and a very precise forbidden bandwidth of frequencies characterize it. It is the flat structure, that we shall call EBG in the shape of dome. To begin the study of this structure, we are going to analyze the coefficients of reflection and transmission feigned. We shall approach then the application of this structure on the environment close to a network of patch antenna, of a micro strip line and a guide of rectangular wave to show the importance of this material in microwave structures.

KEYWORDS: EBG (electromagnetic band gap), form of dome, microwave.

1 INTRODUCTION

These works join within the framework of a continuity of the research on the electromagnetic band gap structures (EBG). Since more than a decade, numerous works were undertaken and published concerning the structures EBG in the field of the high frequencies [4]. We distinguish the circular forms introduced by Pendry [5], the EBG of square shape [6], in the shape of "S" introduced originally by Prosvirnin [7], the EBG in the shape of "Ω" Introduced initially by Saadoum [8],[9]. Such structures introduce generally forbidden bands in the propagation of electromagnetic waves according to the frequency and create besides them resonance, a negative effective permittivity in a narrow band of frequency in the neighborhood of this resonance.

A new artificial element EBG in the shape of dome is finalized for its characteristics of forbidden band in the propagation. The objective of this article is to understand and to highlight the interesting properties of this element with the aim of applications in antennas and in microwave circuits. Therefore, we present the analysis of these structures, made by means of the CST software and we comment their answers in transmission and in reflection.

We present as possible application of this element, the realization of a filtering pass-band by using micro strip lines with an unmetalized ground plan.

A technique for the improvement of the performances of a network of patch antenna, is also suggested.

2 PRESENTATION OF THE NEW STRUCTURE

2.1 THEORETICAL ASPECT OF THIS STRUCTURE

The EBG structure to be studied, consists of two parts: a dielectric substrate and periodic metallic engravings on the top of the substrate. The geometry is similar to the shape of a dome. (figure1)

The mechanism of functioning of this structure can be explained by means of a model of an equivalent actual environment [12] to LC elements grouped as indicated in the figure 1.

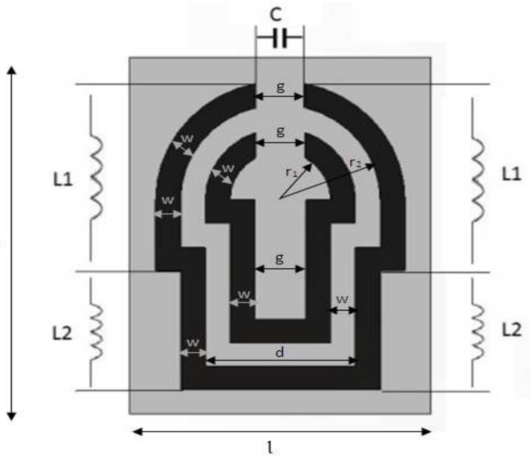

Figure 1: Geometry and dimensions of an electromagnetic band gap (EBG) structure in the shape of dome.

Condensers result from the gap "g" and the inductions result from the current along the metallic part of the patch. The impedance of a parallel resonant circuit LC is given by:

$$Z = \frac{j\omega L}{1 - \omega^2 LC}. \quad (1)$$

The angular frequency of resonance of the circuit is calculated as follows:

$$\omega_0 = \frac{1}{\sqrt{LC}}. \quad (2)$$

In low frequencies, the impedance is inductive and bears TM surface waves. It becomes capacitive for high frequencies, the supported surface waves are the ones of the TE mode. Near the Frequency of resonance, a high impedance is obtained and the EBG does not bear any more surface waves, where from a forbidden frequency band [10] [11].To determine the value of the frequency in theory, we used the Lumped Element method [12].The expression for the inductance of a micro strip line is:

$$L(nH) = 2.10^{-4}.l\left[\ln\left(\frac{l}{w+t}\right) + 1.198 + \frac{w+t}{3l}\right] \quad (3)$$

The inductance of a circular spiral is:

$$L(nH) = 1,257.10^{-3}.\mathrm{a}\left[\ln\left(\frac{a}{w+t}\right) + 0.078\right] \quad (4)$$

With: $a = \frac{D_o + D_i}{4}$ (5)

D_0 and D_i represents respectively the internal and external radius of the spiral.

The expression of the capacity is:

$$C(F) = \varepsilon_r\left(\frac{S}{d}\right) = \varepsilon_r\left(\frac{w*t}{d}\right) \quad (6)$$

(l is the length of themicro strip line,w its length, d is the width of the gap and t the thickness of the used metal)

2.2 DIRECTION OF POLARIZATION OF THE EBG

In this part, four configurations are considered. These configurations are determined with compared with the possible orientations of an EBG inside a guide of waves. So, two of four configurations consist in placing the structure so that the magnetic field H penetrates through rings.Between these two configurations, there is one where the electric field E respects the symmetry of the EBG.

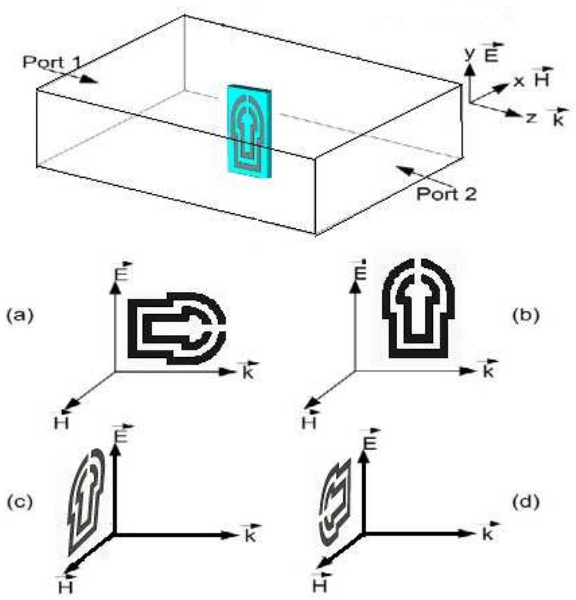

Figure2: The various configurations of the EBG inside the guide of waves.

Thus, the analysis of the resonator is made in four parts (figure2) which are:

- The resonator in the plan (yôz).

Under this configuration, there are two cases:

a) The magnetic field is parallel to the axis of rings:

Both openings are parallel to the small side of the guide of waves and thus the electric field do not respect the symmetry of the resonator (case (a)).

b) The magnetic field is parallel to the axis of rings:

Both openings are parallel to the big side of the guide of waves and thus the field E respects the symmetry of the resonator (case (b)).

The resonator in the plan (xôy).

- There are here also two cases:

c) The magnetic field is perpendicular to the axis of rings:

Both openings are parallel to the big side of the guide of waves and thus the field E respects the symmetry of the resonator (case (c)).

d) The magnetic field is perpendicular to the axis of rings:

Both openings are parallel to the small side of the guide of waves and thus the field E does not respect the symmetry of the resonator (case (d)).

In the case (d), the observed resonance is due only to the electric coupling, while in the case (b), this resonance is due to the magnetic coupling. In the case (a), it is due to a contribution of the electric and magnetic couplings. For the case (c), there is no resonance because there is no magnetic coupling and there is a cancellation of the electric coupling.

The application of an electromagnetic wave on the EBG results in the creation of an induction current in both concentric rings. This current is due either to the electric field or to the magnetic field or both. The curves of transmission for four configurations defined previously are presented on the figure 3.

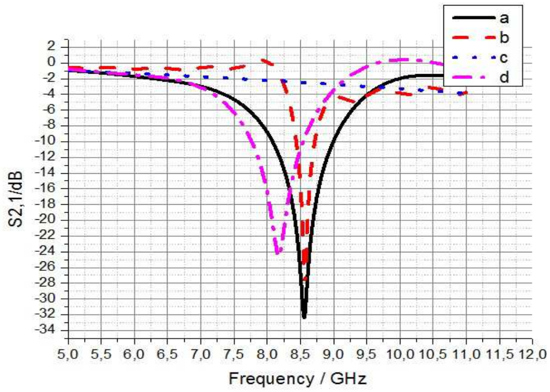

Figure3: Curves of transmission of four configurations of the EBG in a guide of waves.

A behavior cutting-band on narrow frequency band is observed for the cases (a), (b) and (d). On the other hand, in the case (d) , the EBG has no effect on the transmission of the waves in the guide. For the cases (c) and (d), the magnetic field is perpendicular to the axis of rings and thus, does not penetrate through the EBG. Therefore, it does not contribute to the induction currents in the EBG. We can so assert that the induction currents are only caused by the electric field.

For the cases (a) and (b), the magnetic field H penetrates through both rings and generates currents which circulate on these. These currents disappear at the level of the cut and charges of opposite signs accumulate in both extremities of rings, giving birth to an intense electric field in the cut. This is why a resonance is observed in these two cases. The amplitude of the resonance is slightly more raised for the case (a) because we are in the presence of a contribution of two couplings, electric and magnetic.

2.3 Results and simulations

The Resonator in the shape of dome was sized for a functioning in the band C [4 GHz; 8 GHz]. The radius of the external ring is r1=3mm, the width of the copper track is w=0,33mm, the width of the cut of rings is of g=0,33mm, the spacing between both rings is w=0,33mm, the width of the patch is l=4mm and its length is L=5mm. The substrate used for the simulation is the RO4003CR at ROGERS who presents a relative permittivity of 3, 38, tangential losses of the order of 0,0027 and a 0,81mm thickness. This substrate will also be used for all other simulations in this article.

If we apply the equations (3) and (4) with l=2.5mm, w=0.33mm. *t*=0.18mm, d=0.66mm, *Di*=1.33mm and D_0=1.66mm.

The value of the inductance is:

$$L_{eq}(nH) = \sum \left(L_1(nH) + L_2(nH) \right) \quad (7)$$

= 11, 0485.10^{-4}.10^{-3}nH

The value of the capacity is C(F) =0.3042.10^{-3}F

Afterward the value of the frequency of resonance is equal to:

$$f_r = \frac{1}{2\Pi\sqrt{LC}} = 8.68\text{GHz}. \quad (8)$$

The simulations concern the calculation of the coefficients of reflection and transmission of this element.

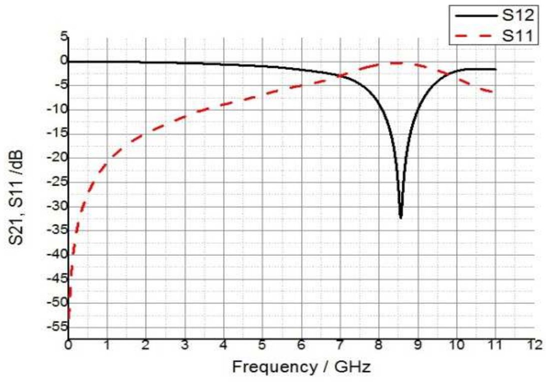

Figure4: The parameters S according to frequency.

The figure 4 shows a frequency of resonance ($f_{rés)}$ to 8.5GHz with a transmission of the order of -35dB.

The figure 5 shows the variation in frequency of the real and imaginary parts of the calculated effective permittivity. We can note that the real part of the permittivity is negative in a narrow band of frequencies around the resonance ($f_{rés}$ = 8.6 GHz) and takes values varying from 0 to -3,5.

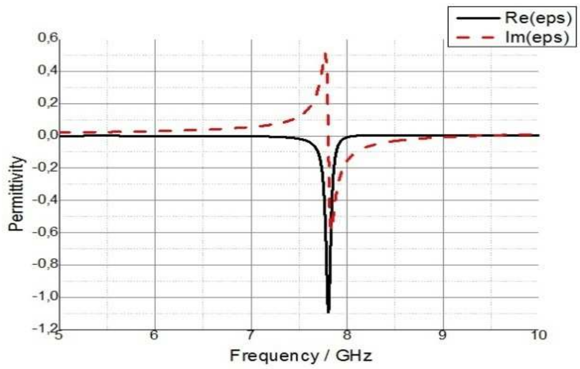

Figure 5: The effective permittivity according to frequency.

3 PRESENTATION OF THE COMPLEMENTARY SHAPE

In this part of this article, we study another resonantstructure which is the Resonator in the shape of complementary dome.

This complementary structure includes two cracks in the shape of concentric interrupted domes made in a conductive plan as indicated in the figure 6.

This shape also has very low dimensions with regard to the wavelength but it must be differently stimulated so that it resounds. It is thus necessary to apply the configuration 4 described in the paragraph 2). The figure 7 shows the coefficients of reflection and transmission in dB.

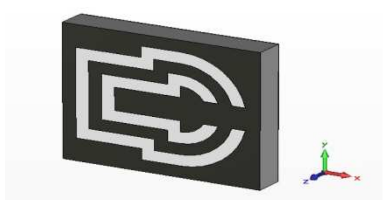

Figure 6: Thecomplementary shape of the EBG in the shape of dome.

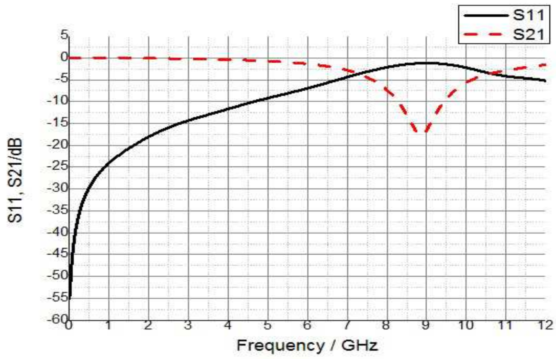

Figure 7: The parameters S according to the frequency.

The study of a periodic network (figure 8) formed by several cells of resonator in the shape of complementary dome allowed us to widen the forbidden band (figure 10). In fact, the juxtaposition of the frequencies rejected by different cells led to a forbidden band of 2.5GHZ, if we admit that the rate of rejection is at the level of -15db.

Figure 8: A periodic network formed by 8 cells in the shape of dome.

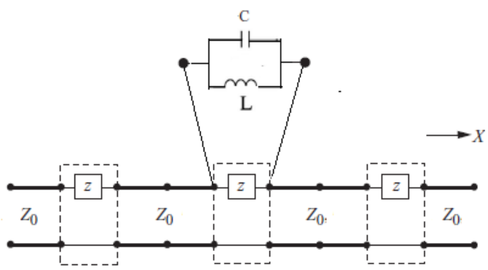

Figure9: A periodic network modelleed with LC elements.

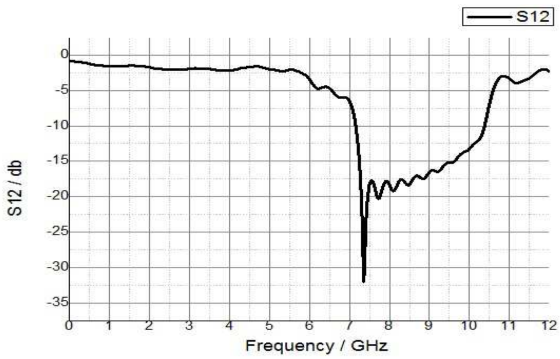

Figure 10: The coefficient of transmission according to the frequency

3.1 GUIDE OF WAVE WITH EBG

The results obtained above and works that have been performed [13] gave us the idea to conceive a guide of wave to forbidden band by replacing both lateral sides (figure11) of a guide by the structure of the figure9,

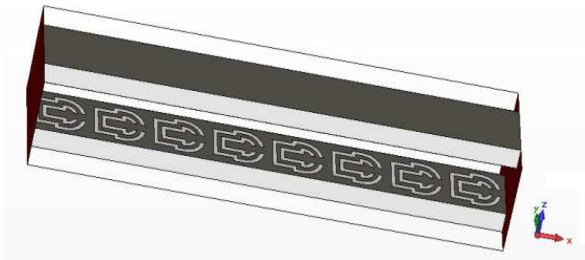

Figure 11: A guide of wave to forbidden band.

This structure is simulated under CST. The coefficient of transmission (S21) is given into the figure12.The result obtained in simulation shows a behavior band gap around the central frequency of 8GHz. In fact, the stimulation of this guide is so that the electric-magnetic coupling is present for every cell of the network.

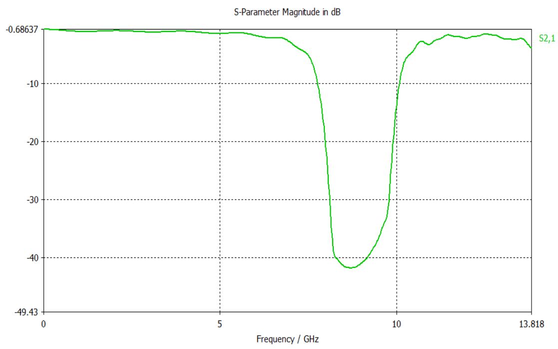

Figure12: The coefficient of transmission according to the frequency.

3.2 A FILTER CUTTING-BAND

These last years, the use of micro-strip lines with unmetallized groundplan allowed reducing the size of circuits in a significant way [14], [15]. We thus direct the study on planar structures and, more exactly on micro-strip lines of characteristic impedance 50ohms, having their unmetallized ground plan by type EBG's cracks in the shape of complementary dome. We shall thus present a new approach for the modeling of planars metamaterials.

This part is dedicated to the modeling of a cutting-band filter, its ground plan is unmetallized with EBG.

First, we present a structure cutting-band obtained by a network of 4 × 4 of the EBG in the shape of complementary dome (Figure 14).

The structure presented on figure 13 will be the ground plan for the filter.

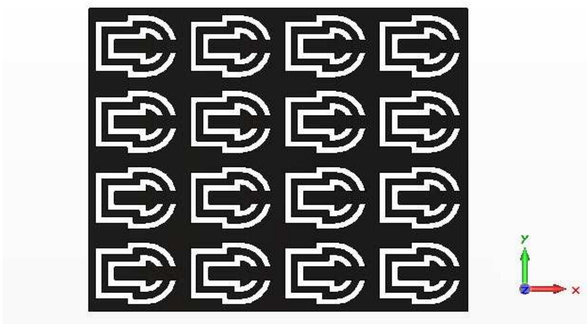

Figure 13: A network of 4 × 4 of the EBG in the shape of complementary dome.

The substrate has 0,81mm as thickness and a surface of 16,52 × 16,52 mm^2.The line of transmission has a 1,858mm as width and a 16,52mm as length. The periodicity of the network of the complementary EBG is 3,63mm and so, the network has 13, 89×13, 89 mm^2 as surface.

The ports of supply are placed in every end of the line and a box of radiation is used to simulate an open structure which shines on the free space.

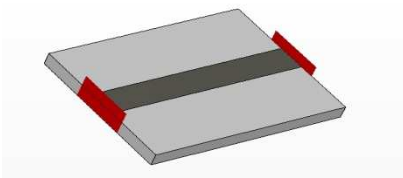

Figure 14: A filter cutting-band (unmetallized mass plan of a micro-strip line 50ohm).

The structure is simulated in the frequency band [5 GHz; 14 GHz] and the results are shown on the figure 15. A behavior cutting-band is obtained in the band [9GHz; 9.5 GHz] around the frequency of resonance of resonators.

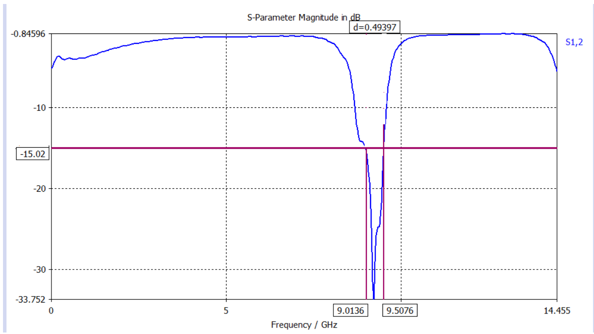

Figure15: The coefficient of transmission S_{12db}according to the frequency.

3.3 Antennas with EBG

Having highlighted the effect of the EBG structure introduced into the mass plan of a micro-strip line,we present now how the EBG in the shape of dome can help to improve the performances of a network of micro-strip antennas. A strong mutual coupling could reduce the efficiency of the network and involve the blindness of the scanning in the multi-elementssystems. Consequently, the structure (EBG) is used to reduce the coupling between the elements of the network[16] ,[17].

Two rows of EBG are inserted between both antennas of the network, as shown in the figure 16. Note that two rows of EBG cells are used here to obtain a satisfactory result.

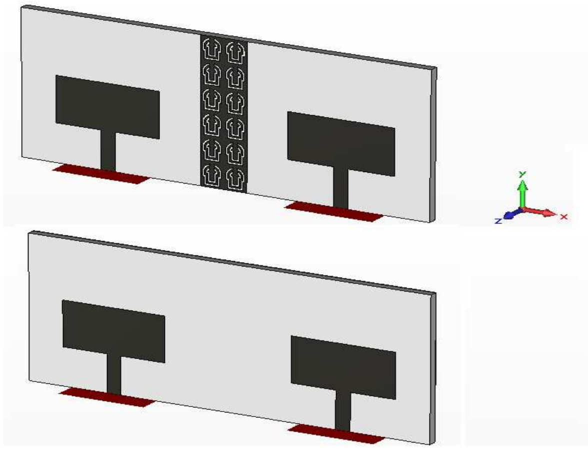

Figure 16: A micro-strip antennas separated by the EBG structures for a low mutual coupling.

CST Microwave Studio is used to simulate the plan E micro-strip antennas coupled on a dielectric substrate with h = 2mm to and ε_r = 10.2. The size of the antennais 7mm ×4 mm and the distance between both antennas is 38.8mm (0.75λ).

We observe that both antennas resound in 6.5GHz witha lossofefficiency superior to 10 dB. For antennas without the EBG structure, the mutual coupling to 6.5GHz is 30dB.In comparison, the mutual coupling of antennas with the structure EBG is-32.5dB. A reduction about 2.5 dB of mutual coupling is realized with the frequency of resonance of 6.5GHz.

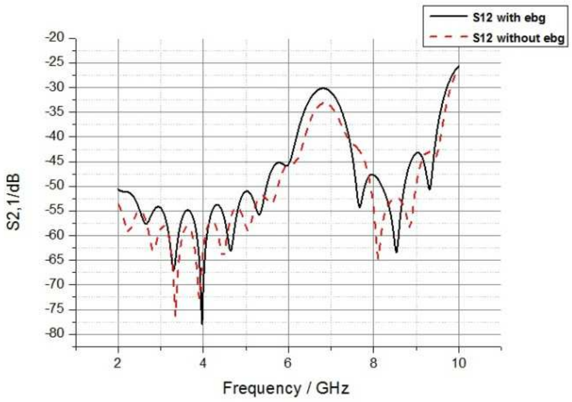

Figure 17: Mutual coupling results of the E-plane coupled patch antennas separated by EBG structures

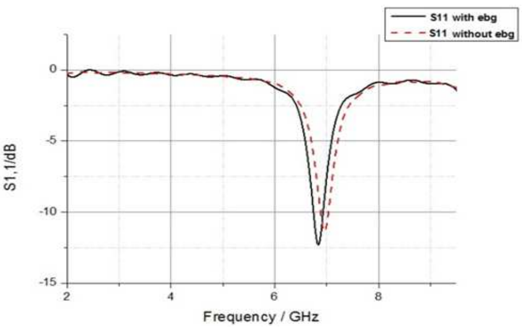

Figure 18: The return loss results $S_{11db}$of the E-plane coupled microstrip antennas separated by EBG structures

4 CONCLUSION

These last years, the structures with electromagnetic band gap (EBG) attracted the interest of several researchers because of their desirable electromagnetic properties that we cannot observe in the natural materials. In this respect, the EBG structure is a subset of metamaterials. Diverse activities of researches on the EBG structures are for the increase in the community of the electromagnetism and the antennas, and a wide rangeof applications was indicated, such as antennas with low profile, the networks of antennas with electronic scanning, the TEM guides of waves and the microwave filters.This article presents a contribution in this domain of research. In fact, this new structure of an EBGin the shape of dome could open the perspectives for other more and more successful forms.

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REFERENCES

[1] B. A. Munk, Frequency Selective Surfaces: Theory and Design, John Wiley & Sons, Inc.,2000.

[2] Y. Rahmat - Samii and H. Mosallaei, “Elec-tro magnetic band-gap structures: classification, characterization and applications,” Proceedings of IEE-ICAP symposium, pp. 560–4, April 2001.

[3] J. D. Joannopoulos, R. D. Meade, and J. N. Winn, Photonic Crystals, Princeton University Press, 1995.

[4] Fan yang , Yahya Rahmat - samii ’’Electro- magnetic Band Gap Structures in Antenna Engineering’’,University of Mississippi, Univer-sity of Californiaat Los Angeles, 2009.

[5] Pendry, J. B., Holden, A. J., Robbins, D. J. and Stewart, W. J., “Magnetismfromconductors and enhanced nonlinearphenomena”, IEEE Transactions on Microwave Theory and Techniques, 47 (1999) 2075.

[6] D. R. Smith, D. C. Vier, N. Kroll, and S. Schultz, “Direct calculation of permeability and permittivity for a left-handed metamaterial”, Applied Physics Letters, vol. 77, no. 14, pp. 2246–2248, October 2000.

[7] S. L. Prosvirnin and S. Zouhdi, “Multi-layered arrays of conducting strips: switchable photonic bandgap structures”, International Journal of Electronics and Communications, vol. 55, no. 4,pp. 260–265, July 2001.

[8] M. M. I. Saadoum and N. Engheta, “A reciprocal phase shifter using novel pseudochiral or Omega medium”, Microwave and Optical Technology Letters, vol. 5, pp. 184–188, April 1992.

[9] B. Sauviac, C. Simovski, and E. Verney, “Métamatériaux semi isotrope à indice négatif à basede motifs "”", in 13èmes Journées Nationales Microondes, Lille, May 2003.

[10] D.F. Sievenpiper , “High Impedance electromagnetic surfaces“ ,Ph.D .dissertation, Electrical Engineering Department, University of California, Los Angeles, 1999.

[11] Sievenpiper, D., L. Zhang, R. F. J. Broas, N. G. Alexopolous, and E. Yablonovitch, “High-impedance electromagnetic surfaces with a forbidden frequency band,” IEEE Trans. Microwave TheoryTech., Vol. 47, 2059–2074, 1999.

[12] Inder Bahl “Lumped elements for RFand microwave circuits“.Artech House microwave library. ISBN 1-58053-309-4,2003.

[13] S.Hrabar,J. Bartolic, and Z. Sipus, “Waveguide miniaturization using uniaxial negative permeability metamaterial”, IEEE Transactions on Antennas and Propagation, vol. 53, no. 1, pp. 110–119, January 2005.

[14] C. C. Chang, Y. Qian, and T. Itoh, “Analysis and applications of Uniplanar Compact Photonic Bandgap structures”, Progress in Electromagnetic Research, vol. 41, pp. 211–235, 2003.

[15] F. R. Yang, Y. Qian, and T. Itoh, “A novel compact micro strip band pass filter with intrinsic spurious suppression”, in Asia Pacific Microwave Conference (APMC’98), -Yokohama, December 1998.

[16] F. Yang and Y. Rahmat-Samii, “A low profile circularly polarized antenna over electromagnetic band-gap (EBG) surface,” Microwave Optical Tech.Lett., vol. 31, no. 4, 264–7, November 2001

[17] S. N. Burokur, M. Latrach, and S. Toutain, “Theoretical investigation of a circular patch antennain the presence of a left-handed medium”, IEEE Antenna and Wireless Propagation Letters, vol4, pp. 183–186, 2005.