Application of Electromagnetic Band Gap (EBG) Materials in Low Profile Antenna Design

Q. Luo[1], J. R. Pereira [2], H. M. Salgado[3]
[1] INESC Porto, Porto, Portugal, qluo@inescporto.pt
[2] IT/Universidade de Aveiro, Campo Universitário, 3810-391 Aveiro, Portugal, jrp@det.ua.pt
[3]INESC Porto/ Faculdade de Engenharia, Universidade do Porto, Portugal, h.salgado@ieee.org

Abstract - **In this paper, the design of low profile antennas by using Electromagnetic Band Gap (EBG) materials is introduced. Several novel EBG surface geometries are proposed based on results obtained by numerical simulations. The simulation results in HFSS 10 show that these EBG structures can exhibit dual band in-phase reflection, or in another words, Artificial Magnetic Conductor characteristics on the WLAN frequency band (2.4/5.2 GHz). One of these EBGs, slot Jerusalem Cross (JCSS) geometry, has been successfully implemented in the design of low profile WLAN coplanar and PIFA antennas. Both antennas have been fabricated and the measurement results are presented. Furthermore, the further research trend in EBG design is also discussed**.

I. INTRODUCTION

Many studies have been conducted in antenna design using a new type of material: Electromagnetic Band Gap (EBG) materials, which exhibit high surface impedance and can behave as a Perfect Magnetic Conductor (PMC) over certain frequency band(s) [1]. EBG materials are always constituted by periodically dielectric or metallic structures that can act as small resonant LC circuit [2]. In the application of antenna design, Metallic EBG (MEBG) has always attracted research interest due to its advantages of easy fabrication, compact size and conformable with Monolithic Microwave Integrated Circuit (MMIC) technology. Figure 1 presents one of the most classic and famous MEBG structure, *mushroom-like EBG*, proposed by Sievenpiper.

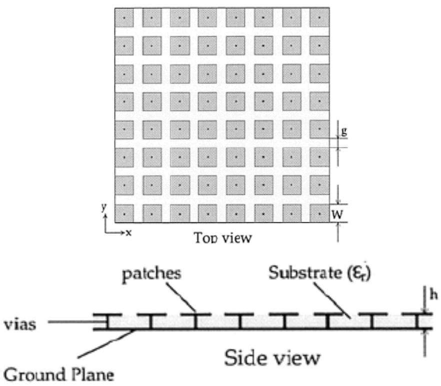


Fig.1Geometry of a mushroom-like EBG structure [3]

The EBG structure presented above consists of by an array of square patches on one side of the substrate and a ground plane on the other side. The size of each square patch is *w* with spacing *t* between each unit cells. Figure 2 shows the equivalent LC circuit for this EBG structure.

Fig.2 The equivalent LC circuit of a simple EBG structure [4]

If the values of capacitor and inductance have been evaluated, the resonant frequency can be worked by using:

$$w_0 = \frac{1}{(LC)^{1/2}} \quad (1)$$

and the bandwidth can be calculated by the formula:

$$BW = \frac{(f_U - f_L)}{f_c} \quad (2)$$

where f_U,f_C, f_L are the frequencies that has reflection phase of -90, 0 and +90 degrees occurs, respectively [5-6]. Moreover, in [6] it is shown that the bandwidth is proportional to $(L/C)^{½}$:

$$B \propto (\mathrm{LC})^{1/2} \quad (3)$$

The parametric study of the mushroom-like EBG structure regarding how to either increase or decrease the value of inductance L and conductor C is suggested in [1]. Compared to conventional Perfect Electric Conductor (PEC) ground plane, the usage of MEBG ground plane for antennas has two significant advantages [1] [3]:

1. The reflection phase of EBG is "in phase". For a PEC, the reflection phase is reversed compared to the incident wave; but the EBG can provide continuous reflection phase from -180 to +180 degrees (figure 3). In this case, the EBG surface is also called High Impedance Surface (HIP) or Artificial Magnetic Conductor (AMC).

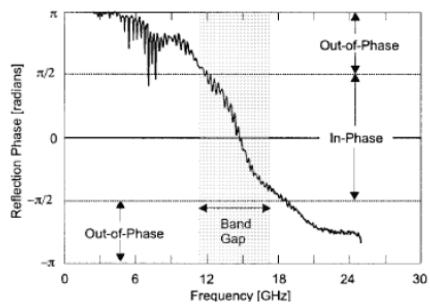


Fig. 3 The reflection phase of EBG [6]

2. The surface wave can be suppressed by the EBG, which means that the radio-frequency current can be radiated more efficiently.

The AMC characteristic of MEBG has applications in low profile antenna design. The constraint of the minimum height of the wired antenna being $\lambda/4$, where λ is the wavelength of the resonant frequency of the antenna, can be overcome by using EBG materials as the ground plane. This characteristic is very useful to compact antenna designs in applications with limit space available [6-8]. The applications of EBG in low profile coplanar antenna and Planar Invert-F antenna (PIFA) also have been proposed recently [9-10].

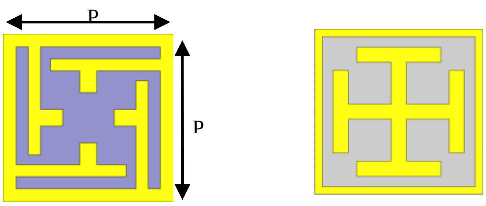
Nowadays, EBG materials have gained wide applications in Microwave and RF areas as they exhibit many merits in antenna design such as reducing antenna size, increasing antenna working efficiency and reducing backward radiation [6]. Compact design and wide bandwidth are two of the most important and also difficult aspects in EBG design. Ideally, if its size can be further reduced, the application of EBG materials can include the area of personal portable communications.

II. THE APPLICATION OF MEBG IN LOW PROFILE ANTENNA DESIGN

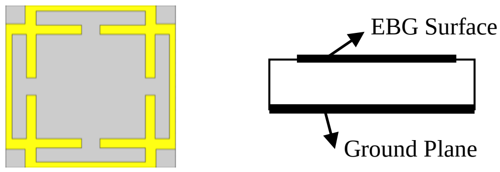
In this section, some applications of MEBG in low profile antenna design will be introduced. To start, some new geometries of MEBG structure will be presented. Then, two low profile EBG antenna design will be introduced.

As we are more interested in low profile antenna design, the AMC characteristics of the EBG structure is the only concern in this paper. The bandwidth of EBG mentioned in this context follows the classic definition, which is reflection phase from -90 to +90 degrees.

It is has been proved that EBG can effectively contributed to the design of low profile antenna. However, most of the well-known EBG structures are only single band with the fact that multiband EBG is needed for the multiband communications. Multiband EBG design is more challenging because of the increase in complexity. Figure 4 shows three novel EBG unit cell geometries that we proposed for the possible application in WLAN antenna design. All of these EBG structures have a period of *P* mm and have been designed on Roger 3010 (ε_r = 10.2) with thickness of 1.27 mm.



(a) (b)



(c) (d)

Fig.4 The surfrace geometry of (a) modified slot EBG, (b) the slot Jerusalem Cross (JCSS) EBG, (c) the multi-slot EBG and (d) the size view of the EBG unite cell

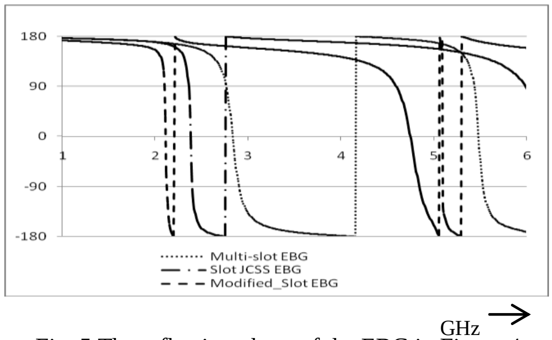


Fig. 5 The reflection phase of the EBG in Figure 4

Figure 5 shows the simulated reflection phase of the EBG stuctures given in figure 4. More details of these EBG can be found in table 1.

Table 1 Reflection phase of MEBG shown in Figure 4

	Cell Size P (mm)	f_{c1} (GHz)	Bw1 (%)	f_{c2} (GHz)	Bw2 (%)
modified slot EBG	14	2.12	1	4.75	5
slot JCSS EBG	11	2.38	1.68	6.21	7.25
multi-slot EBG	14	2.8	5	5.48	1.82

From table 1, it is found that the EBG surface geometry is crutial to the reflection phase as well as the bandwidth of the EBG. For example, with the same size, the bandwidth of “multi-slot EBG ”at 2 GHz band is 5 times as the “modified slot EBG”. Figure 6 shows the fabricated EBG ground planes with arrays of 5×5 and 4×4 unit cells with total size of 6×6 mm respectively.

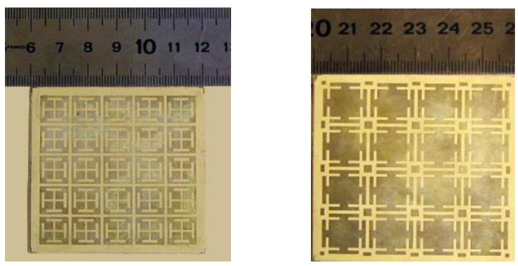


Fig.6 Fabricated EBG with geometry of (left) Slot JCSS (right) Multi-Slot

One of the EBGs that have been introduced above, the JCSS slot EBG has been successfully used in the low profile coplanar antenna designed for WLAN communications (2.4/5.2 GHz) (figure 7).

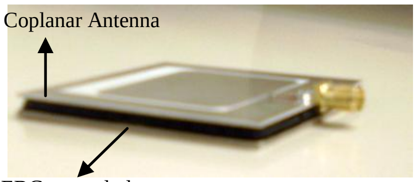
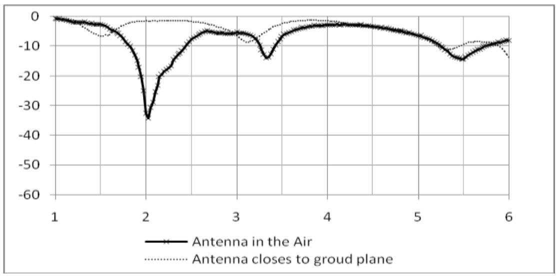
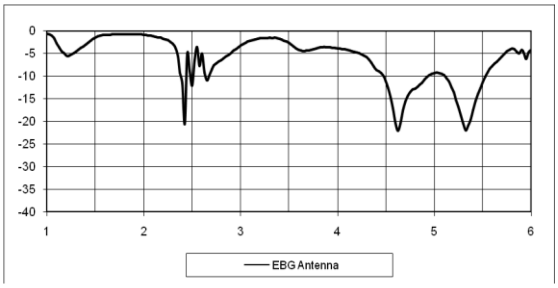


Fig.7 The fabricated EBG Coplanar antenna

In figure 7 the coplanar antenna that resonates as a monopole antenna in free space, is positioned at only 3mm above the EBG ground plane. Normally, the coplanar antenna cannot work properly if it is too close to a PEC ground plane unless the minimum height is λ/4, where λ is the lowest resonant frequency. However, by using the EBG as the AMC ground plane, although some bandwidth reduction is observed, this antenna can still be operated at the desired frequency with increased gain. Moreover, the study also found that the backward radiation is also reduced to a promising level, which is good for applications such as body worn antenna. Figure 8(a) shows the return loss (S11) of the coplanar measured in the free space and close to a PEC the ground. Figure 8(b) shows the S11 of the proposed EBG Coplanar antenna, in which the coplanar antenna is positioned at only 3 mm above the EBG ground plane.



(a)



(b)

Fig. 8 (a) Measured S11 of the coplanar antenna in free space and 3 mm above a PEC ground plane; (b) measured S11 of the coplanar antenna positioned at 3mm above the proposed EBG ground plane

Figure 9 presents the comparison of measured radiation patterns between the coplanar antenna resonant in free space and the proposed EBG coplanar antenna at 2.4 GHz band in both E and H plane. It can be seen that the use of the EBG as a ground plane improves the gain by 2 dB and there is a 5 dB reduction on the back lobe in both bands. The similar results are also observed at 5 GHz band.

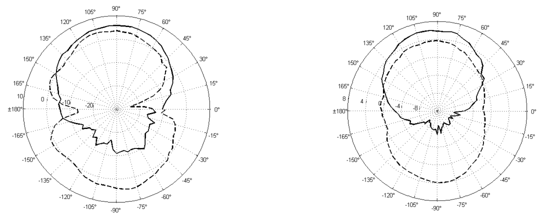


Fig. 9 Comparison between measured radiation pattern of reference antenna (dashed line) and EBG antenna (solid line)

Similarly, one low profile EBG U-Slot PIFA antenna (figure 10) was also implemented using the same EBG geometries with different parameters and array size. The diameter of the short pin and probe feed are chosen to be 0.5 mm in order to make sure that both pins can just fit in the gap of EBG cells and will not inference the periodicity of EBG as well as induce some unnecessary surface current. In this design, the height of the PIFA antenna is reduced from 9 mm, which is the original parameters in [11], to only 2.7 mm. This means that 70% of height reduction is achieved. Most interestingly, the bandwidth at the 5 GHz band has been improved by nearly 10 times. Therefore, in this case, the use of an EBG ground plane made possible to achieve the design of an antenna simultaneous with a low profile and a wide bandwidth.

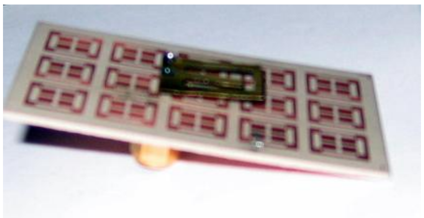
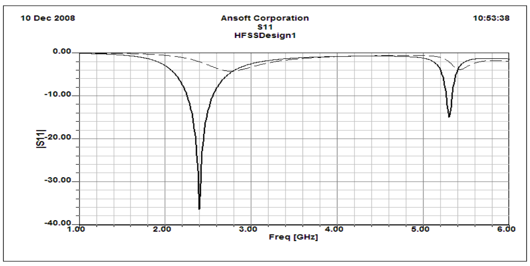
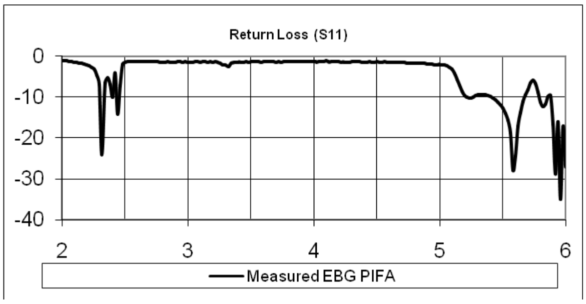


Fig. 10 The fabricated EBG PIFA antenna

Figure 11 (a) shows the simulated return loss (S11) of the U-Slot PIFA placed at 9mm and 2.7mm above the ground plane. Figure 10 (b) shows the measured S11 of the EBG PIFA, which has a total thickness of only4 mm including the thickness of the EBG (1.27 mm). This proposed antenna is almost 50% thinner than the original design in [11]. Figure 12 presents the measured far field radiation pattern of this EBG-PIFA antenna in both E-and H-plane. This antenna has maximum gain of 4 dB with less than-10 dB back lobe radiation in both bands.



(a)



(b)

Fig. 11 (a) The S11 of the U-Slot PIFA antenna placed 9 mm above a PEC ground plane as proposed in [11] (solid line) and 2.7 mm above a PEC ground plane (dash line); (b) the measured S11 of proposed EBG coplanar antenna

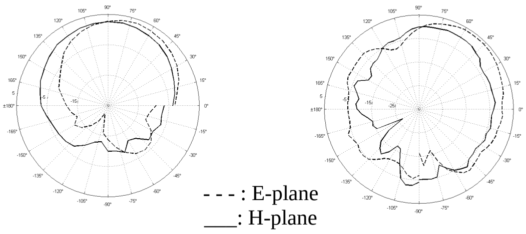


Fig. 12 Radiation patterns of 2.42GHz (left) and 5.56 GHz (right)

III. CONCLUSIONS AND FUTURE RESEARCH

In this paper, the concept of EBG structure working as the AMC ground plane has been introduced. Moreover, some novel EBG surface geometries have also been presented. The Slot-JCSS EBG structure has been successfully implemented in the low profile coplanar and U-slot PIFA antenna design, both of which are designed to work at the WLAN frequency (2.4/5.2 GHz). From the simulation and measurement results, it is concluded that the use of EBG as the ground plane is an effective technique for the design of low profile antennas. Furthermore, it is shown that it is possible to achieve a low profile structure and wide operation band simultaneously.

Recently, reconfigurable antenna design has attracted many research interests. Researchers start to adopt previous known reconfigurable techniques into MEBG design. In this way, *reconfigurable EBG* or *active EBG* design becomes possible. In [12], some RF switches have been added to the mushroom like EBG and the results show that the reflection phase of this EBG can be changed by switching on/off the PIN diodes. Furthermore, in [13], the authors also found that by putting a wired dipole antenna very close to an EBG ground plane formed by arrays of mushroom like EBG, the radiation beam of the antenna can be shift by reconfiguration of the EBG surface. Possible application of this concept is in the design of base station antennas in the street. In addition, the application of active EBG techniques in the design of reconfigurable antennas or antenna arrays is also a topic worth exploring.

REFERENCES

[1] F. Yang and Y. Rahmat-Samii, “Reflection phase characteristics of the EBG ground plane for low profile wire antenna applications”, *IEEE Trans on Microwave theory and Tech.* , Vol. 51, NO. 10, October, 2003

[2] H.Mosallaei and K.Sarabandi, “A compact wide-band EBG structure utilizing embedded resonant circuits”, *IEEE Trans on Antenna and Wireless Propagation Letters*, Vol. 4, 2005

[3] D. Sievenpiper, “High-impedance electromagnetic surfaces,” PhD dissertation, Dept. Elect. Eng., Univ. California at Los Angeles, Los Angeles, CA, 1999

[4] G. Poilasne, “Antenna on high impedance ground planes: on the importance of the antenna isolation”, Progress in Electromagnetic Research, PIER 41, pp.237-255,2003

[5] D. J. Kern, D. H. Werner, A. Monorchio, L.Lanuzza and M. j.Wilhelm, “The design synthesis of multiband artificial magnetic conductors using high impedance frequency selective surfaces”, IEEE Trans on Antenna and Propagation, Vol. 53, NO. 1, January, 2005

[6] D. Sievenpiper, L. Zhang, R. F. J. Broas, N.G. Alexopolous and E. Yablonovitch, “High-Impedance Electromagnetic Surface with a Forbidden Frequency Band”, IEEE Trans on Microwave theory and Tech., Vol. 47, NO. 11, November, 1999

[7] E.R.Brown, O.B.McMahon and C.D.Parker, “Photonic-Crystal antenna substrate”, Lincoln Laboratory Journal, Vol 11, No.2, 1998

[8] M.F. Abedian, M. Ali, “Effects of EBG Reflection phase profiles on the input impedance and bandwidth of ultrathin directional dipoles", IEEE Trans on Antenna and Propagation, Vol. 53, NO. 11, November, 2005

[9] Q. Luo, H.M. Salgado, A.M. Moura and J.R. Pereira, “Dual-band antenna design using an EBG Artificial Magnetic Conductor Ground Plane”, Antennas and Propagation Conference LAPC 2008, pp. 217-220, 17-18 March 2008

[10] Q. Luo, H.M. Salgado, and J.R. Pereira, “EBG PIFA design for WLAN application”, IEEE Antennas and Propagation Society International Symposium, AP-S 200. pp. 1-4, 5-11 July 2008

[11] P. Salonen, M. Keskilammi, and M.Kivikoski1, “New Slot Configurations for Dual-Band Planar Inverted-F Antenna”, *Microwave and Optical Technology Letters*, Vol. 28, No. 5, March 5 2001

[12] K. L. Ford, H. J. Lee and R. J. Langley, “Tuneable Compact Antenna Design using Active EBGs”, *Antenna and Propagation Society International Symposium*, pp. 2925-2928, June 2007

[13] K. L. Ford and J. M. Rigelsford, “Dipole radiation steering using an active artificial magnetic conductor”, *Antenna and Propagation Society International Symposium 2008*, July 2008