POS-A-29

Improvements on a Planar Inverted-F Antenna using Electromagnetic Band-Gap structures

L. C. Kretly, *Member IEEE*, Alexandre M. P. Alves S.

Electrical and Computer Engineering Faculty at State University of Campinas, UNICAMP, Campinas, Sao Paulo, Brazil. E-mails: kretly@dmo.fee.unicamp.br, ampas@dmo.fee.unicamp.br

Abstract— **This paper presents the effect of an EBG, Electromagnetic Band-Gap, structure as the ground plane of a PIFA, Planar Inverted-F Antenna. The PIFA is a type of antenna which has been used in many communication applications. It is a medium bandwidth radiator with reduced dimensions.**

The EBG structures have special electromagnetic properties such as high surface impedance and suppression of propagating surface currents within a frequency band, called band-gap, which are very useful for wireless applications. The EBG presented is the mushroom-like EBG structure and it is used as the antenna ground plane to improve some antenna characteristics such as bandwidth, gain and directivity.

Index Terms— **Electromagnetic band-gap, EBG, high surface impedance, band-gap, surface waves, PIFA, ground plane.**

I. INTRODUCTION

FOR wireless communication systems it is always necessary to improve some antenna characteristics. This is normally achieved by increasing some antenna dimensions or using antenna arrays. On the other hand, there are the requirements for this wireless systems. For some applications, one of these requirements is to have the smallest antenna dimensions as possible.

The PIFA, Planar Inverted-F Antenna, is a type of antenna which already has small dimensions and light weight. To improve the antenna characteristics as bandwidth, directivity and gain, without increase its dimensions, it could be used a perfect magnetic conductor as its ground plane. It improves the antennas performance by the creation of their equiverse image currents, but this material is only theoretical [1].

Structures that exhibit the perfect magnetic conductor properties within a frequency band are classified under the broad terminology of "meta-materials" or EBG, Electromagnetic Band-Gap [2]. EBG structures are periodic objects that present high impedance surface and prevent the propagation of electromagnetic waves within a specified frequency band, called bandgap. The EBG structure used in this paper is the mushroom-like EBG structure, also called AMC, Artificial Magnetic Conductor, proposed by Sievenpiper *et al.* [3].

The aim of this paper is to analyze the improvements achieved on a PIFA antenna by the use of an EBG structure as its ground plane and without changing the designed radiator dimensions.

II. ELECTROMAGNETIC BAND-GAP STRUCTURE DESIGN

The EBG presented in this paper is a metal-dielectric structure which has a special texture. It is composed by a top capacitive FSS, Frequency Selective Surface, layer; a bottom metal layer and a bed of nails (via array) embedded in a dielectric substrate connecting them, as depicted in Fig. 1.

The FSS layer can vary in shape but it is essentially a two-dimensional sheet of disconnected metal obstacles [4]. The number of FSS layers could be more than one but, in this work, it is used just one FSS layer composed by hexagonal metal patches. A patch is, in this case, a cell for the structure.
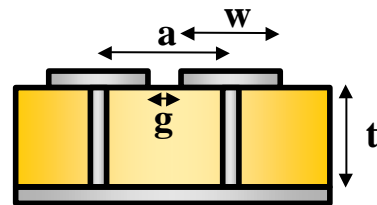

Fig. 1. Lateral EBG structure view.

The mushroom-like EBG structure behaves as a resonant LC circuit where, near the resonance frequency, it shows a high surface impedance. The capacitance is provided by fringing electric fields between adjacent cells and the inductance by the conducting path linking them. As a resonant LC circuit, the resonance frequency is given by [3]:

$$\omega = \left(\sqrt{L.C}\right)^{-1}, \tag{1}$$

$$L = \mu.t, \tag{2}$$

$$C = \left[w.\left(\varepsilon_1 + \varepsilon_2\right).\cosh^{-1}\left(a/g\right)\right]/\pi, \tag{3}$$

where L is the sheet inductance and C is the sheet capacitance; t is the structure thickness; μ is the circuit board material magnetic permeability, which value is the unity at microwave frequencies; w is the capacitor width; ε_1 and ε_2 are the circuit board material and the surrounding space dielectric constants respectively; a is the vias center-to-center spacing; and g is the gap between the cells. It is chosen a hexagonal shape in a triangular lattice for the cells.

The band-gap produced by the EBG structure has its bandwidth given approximately by [5]:

$$BW = 2.\pi.t/\lambda_0, \tag{4}$$

where λ_0 is the wavelength in free space, therefore, the calculated bandgap is 8% at 2.4 GHz.

Using the equations 1, 2 and 3 for a standard fiberglass circuit board ($\varepsilon \approx 4.4$, t = 1.6 mm) and a gap of 0.3 mm

between the cells, it was calculated a cell width of nearly 15 mm.

The EBG formulation presented is very simplified, however, its results are good. A more accurate but complex model can be found in [4] and [6].

The calculated cell width is very large for mobile handsets, however, it could be used on ERBs, picoERBs, WLAN or other wireless applications. One way to reduce the cell width is using more than one FSS layer, as shown in [7]. It is chosen to built the prototype with one FSS layer due to the prototyping facilities available.

III. PLANAR INVERTED-F ANTENNA DESIGN

A PIFA antenna is like a quarter-wave monopole antenna folded parallel to the ground plane and stretched to form a plate [8]. The name PIFA is due to its side profile that looks like an inverted F figure, as depicted in Fig. 2. The classical PIFA antenna ground plane is a planar metal sheet on the top of the dielectric layer.
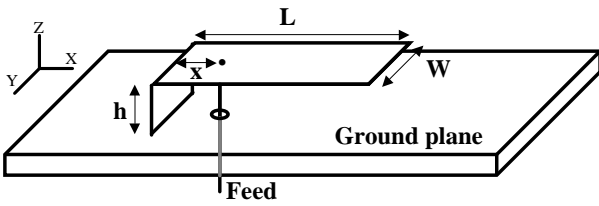

Fig. 2. PIFA Antenna Geometry.

The PIFA is designed to operate at 2.4 GHz by the equation 5 and the software IE3D (MoM).

$$f_r = c \left[4\alpha \left(W + L \right) \right]^{-1} \quad (5)$$

where c is the velocity of light, α is a constant approximately equal to 0.9, W and L are, respectively, the antenna width and length. The x parameter, shown in Fig. 2, is defined as the distance from the feed line to the PIFA's shortened edge, and controls the antenna matching [9].

The final PIFA antenna dimensions are $W = 11\ mm$, $L = 27\ mm$, $h = 7.5\ mm$ and $x = 7.2\ mm$ on a ground plane of $130 \times 70\ mm^2$. The prototype is shown in Fig. 3.

The comparison between the simulated and measured S_{11} parameter for the PIFA antenna is depicted in Fig. 4.

It is observed from Fig. 4 that the simulated bandwidth, according to the $S_{11} <$-10 dB criterion, is 6,7%, and the measured bandwidth is 7.5%. The measured resonant frequency is at $2.41 GHz$. The simulated classical PIFA has directivity D=4.26 dB, efficiency $\eta = 95.71\%$ and gain G=4.08 dB.
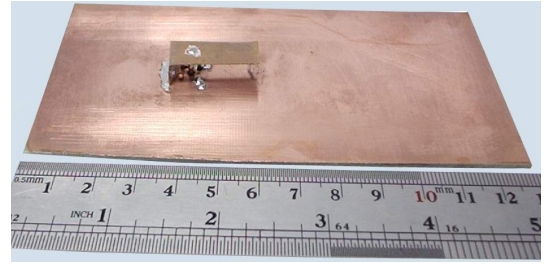
(a) Top view.
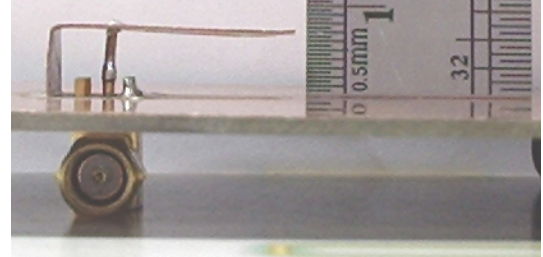
(b) Side view.

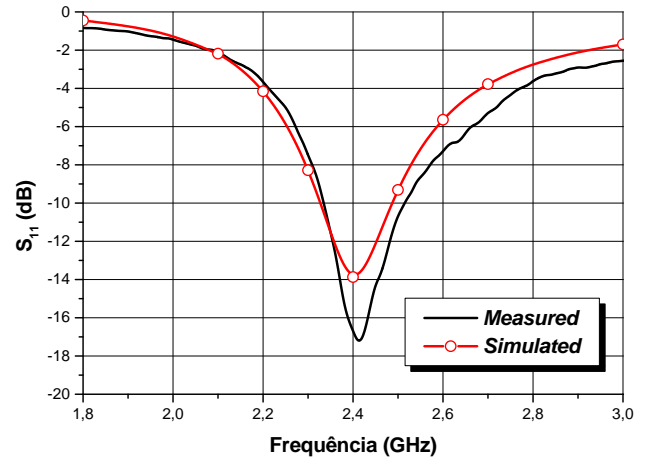Fig. 3. The PIFA antenna on a classical ground plane prototype views (the reference ruler is in cm and inches).

Fig. 4. Measured and simulated S_{11} parameter for PIFA antenna prototype.

IV. PIFA ANTENNA ON THE EBG GROUND PLANE

In this section is presented the designed EBG structure as the ground plane of the designed PIFA antenna. The prototype is shown in Fig. 5 and its total dimensions are $170 \times 135\ mm^2$.

It is also analyzed the PIFA antenna on EBG with a LGP, Local Ground Plane. The LGP is a small classical ground plane emulated by short-circuiting the three nearest cells just below the antenna. The LGP is used to observe the effect of the EBG structure surrounding a classical PIFA. The measured S_{11} comparison among the three ground plane configurations is depicted in Fig. 6.
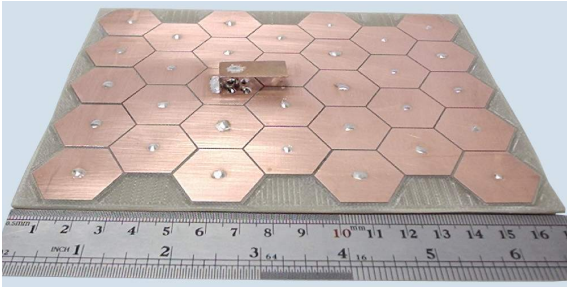
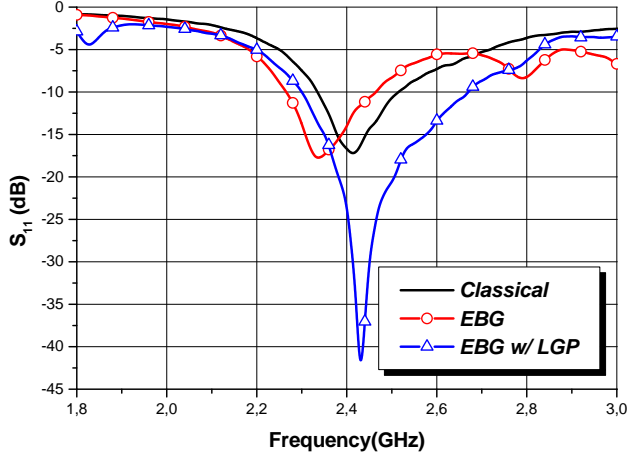Fig. 5. The PIFA on EBG prototype (the reference ruler is in cm and inches).

Fig. 6. Measured S_{11} results for the classical PIFA, the PIFA on EBG and the PIFA on EBG with LGP.

In Fig. 6 the classical PIFA antenna has a bandwidth of 7.5%; the PIFA on EBG has a bandwidth of 8.3%; and the PIFA on EBG with LGP has a bandwidth of 15.4%, this is more than twice the classical PIFA bandwidth. The PIFA on EBG resonant frequency is at 2.34 GHz and the PIFA on EBG with LGP is at 2.43 GHz. The other simulated and measured characteristics are shown in Table I.

TABLE I
RESUME OF THE PROTOTYPE CHARACTERISTICS

Prototype	Resonance Frequency	Directivity	Gain	Bandwidth
	(GHz)	(dB)	(dB)	(MHz)
PIFA	2.4	4.26	4.08	170
PIFA on EBG	2.42	5.21	4.83	200
PIFA on EBG with LGP	2.43	4.76	4.20	370

The table above shows that the major improvement is on bandwidth, but the overall antenna performance are improved.

It is also measured the radiation patterns of the three ground plane configurations in an anechoic chamber at CTA/ITA. The measurements are made in a vertical polarization at 2.4 GHz and are depicted in Fig. 7. The radiation pattern planes have the same coordinate system of the Fig. 2.
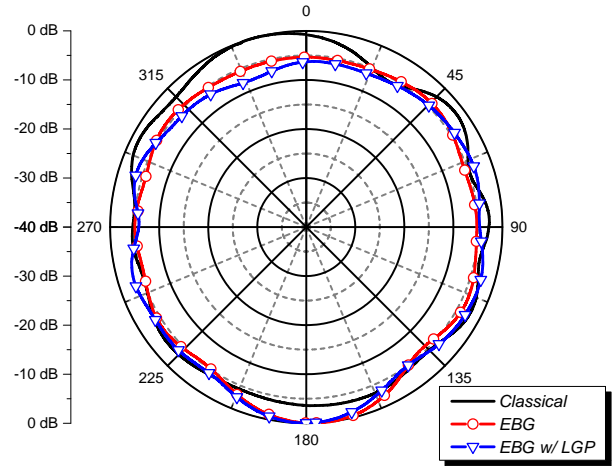
(a) X-Y plane.
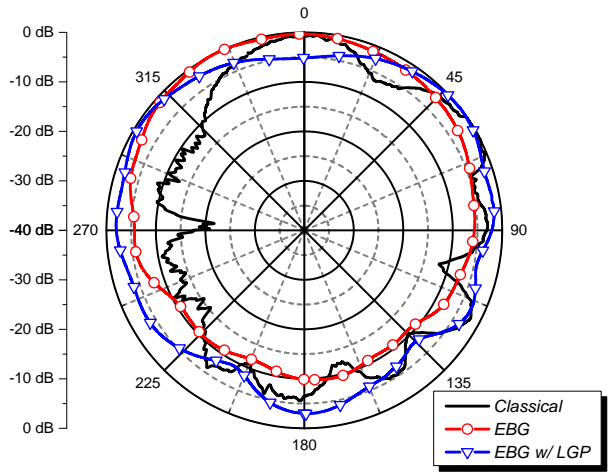
(b) Z-Y plane.

Fig. 7. Measured 2D radiation pattern for the three ground planes configurations at 2.4 GHz.

The Fig. 7(b) shows that all radiation patterns for the different ground plane configurations, in the X-Y plane, are almost omnidirectional. From Fig. 7(b) it is possible to observe that the radiation patterns, in the Z-Y plane, for the PIFA on EBG ground plane with and without LGP are more omnidirectional than the one for the PIFA on the classical ground plane. This is desirable for mobile applications antennas such as handsets, laptops and others that need this radiation model.

V. CONCLUSION

It is showed, by measurements and simulations, the improvement on PIFA antenna characteristics, achieved by the use of an EBG structure as the antenna ground plane. The major improvement is on the bandwidth, mainly when is used the LGP, which is more than twice the classical PIFA antenna bandwidth. To achieve a bandwidth value of 15,4%, the PIFA antenna on classical ground plane dimensions should be much bigger than the dimensions presented here.

The directivity and the gain are also improved on both EBG ground planes configurations. The resonant frequency of the antenna on the EBG is shifted, but it is an expected effect for periodic structures. The radiation patterns suffered the effect of the new ground plane configurations, becoming more omnidirectional on the case of Z-Y plane.

The designed EBG structure has cells with dimensions not proper for mobile handsets but can be used in ERBs, WLAN and other wireless applications. EBG structures can have smaller cells than the presented, but it is need a material with a greater dielectric constant or more than one FSS layer. However, the results achieved show that the EBG structure really improve the antenna characteristics without increasing the antenna dimensions.

REFERENCES

[1] D. Sievenpiper, R. Broas, and E. Yablonovitch, "Antennas on high-impedance ground planes," *IEEE MTT-S International Microwave Symposium Digest*, vol. 3, pp. 1245–1248, 1999.

[2] Y. Rahmat-Samii, "The marvels of electromagnetic band gap (ebg) structures: Novel microwave and opticap applications," vol. 1, September 2003, pp. 265–275.

[3] D. F. Sievenpiper, "High-impedance eletromagnetic surfaces," *Ph.D. dissertation, UCLA electrical department*, January 1999.

[4] S. Clavijo, R. Diaz, and W. McKinzie, "Design methodology for sievenpiper high-impedance surfaces: an artificial magnetic conductor for positive gain electrically small antennas," *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 10, pp. 2678–2690, October 2003.

[5] W. E. McKinzie and R. R. Fahr, "A low profile polarization diversity antenna built on an artificial magnetic conductor," *IEEE Antennas and Propagation Society International Symposium*, vol. 1, pp. 762–765, 2002.

[6] M. Rahman and M. A. Stuchly, "Transmission line-periodic circuit representation of planar microwave photonic bandgap structures," *Microwave Opt. Technol. Lett.*, vol. 30, no. 1, pp. 15–19, July 2001.

[7] L. C. Kretly and A. M. P. A. Silva, "The influence of the height variation on the frequency bandgap in an amc, artificial magnetic conductor, for wireless applications: an em experimental design approach," *Proceedings of the 2003 SBMO/IEEE MTT-S International*, vol. 1, pp. 219–223, September 2003.

[8] L. C. Kretly, A. C. SodreJr., and A. A. S. Tavora, "Triangle PIFA antenna array prototype for wireless system applications," *IEEE ITS 2002 International Telecommunications Symposium, (CD)*, September 2002.

[9] A. Muscat and C. Parini, "Novel compact handset antenna," *International Conference on Antennas and Propagation*, no. 480, pp. 336–339, April 2001.