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 which 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.](image)

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]:

\[
\omega = \left(\sqrt{L/C}\right)^{-1},
\]

\[
L = \mu.\pi.t,
\]

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

where \(L\) is the sheet inductance and \(C\) is the sheet capacitance; \(t\) is the structure thickness; \(\mu\) is the circuit board material magnetic permeability, which value is the unity at microwave frequencies; \(w\) is the capacitor width; \(\varepsilon_1\) and \(\varepsilon_2\) are the circuit board material and the surrounding space dielectric constants respectively; \(a\) is the via 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]:

\[
BW = 2.\pi.t/\lambda_0,
\]

where \(\lambda_0\) 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 build 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.

\[ f_r = \frac{c \alpha}{4 \alpha (W + L)} \]  

where \( c \) is the velocity of light, \( \alpha \) 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 \( W = 11 \text{ mm}, L = 27 \text{ mm}, \ h = 7.5 \text{ mm} \) and \( x = 7.2 \text{ mm} \) on a ground plane of 130x70 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 \( S_{11} < -10 \text{ dB} \) 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 \( D = 4.26 \text{ dB} \), efficiency \( \eta = 95.71\% \) and gain \( G = 4.08 \text{ dB} \).

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 170x135 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**

<table>
<thead>
<tr>
<th>Prototype</th>
<th>Resonance Frequency (GHz)</th>
<th>Directivity (dB)</th>
<th>Gain (dB)</th>
<th>Bandwidth (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIFA</td>
<td>2.4</td>
<td>4.26</td>
<td>4.08</td>
<td>170</td>
</tr>
<tr>
<td>PIFA on EBG</td>
<td>2.42</td>
<td>5.21</td>
<td>4.83</td>
<td>200</td>
</tr>
<tr>
<td>PIFA on EBG with LGP</td>
<td>2.43</td>
<td>4.76</td>
<td>4.20</td>
<td>370</td>
</tr>
</tbody>
</table>

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.

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