Fractal Antenna over EBG Structure for UHF RFID Applications

Angel Slavov, Peter Petkov

Abstract—**This paper examines the possibility of developing a low profile antenna with fractal design which can achieve high gain for RFID applications in the frequency range from 865 to 868MHz. The advantages of the suggested structure are high gain, small physical dimensions and low profile compared to traditional antennas. The proposed approach is applicable to EMI/EMC sensors and probes as well.**

Keywords—**EBG, gain, RFID, fractal, low-profile antenna**

I. Introduction

Modern antenna technologies have evolved extremely and rapidly in the latest years. One of the driving reason of that evolution is so-called metamaterials. In this paper we will focus on a specific part of metamaterials namely Electromag- netic Band Gap structures (EBG). These metamatirials exhibit electromagnetic features which may not exist in nature. As it mentioned in [1]. these materials have simultaneously $\varepsilon < 0$ and $\mu < 0$. This type of structure is applicable to a wide range of applications in antenna and propagation fields. For instance it can be used as of spiral and curl antennas to achieve low profile design. [2].

One of the most interesting properties of metamaterials is the reflection phase. It is defined as a phase of the reflected electric field at the reflecting surface compared to the incident one. [3]. It is known that a perfect electric conductor (PEC) has 180^0 reflection phase for a normal incident plane wave. A perfect magnetic conductor (PMC) has a reflection phase 0^0 but does not exist in nature. [1], [3].

However, EBG structures are more than a PMC surface. The reflection phase of the EBG surface varies from 180^0 to -180^0 versus frequency, not only 180^0 for the PEC surface or 0^0 for the PMC surface. This reflection phase feature makes EBG unique. For example one possible application of that surface is its usage as a ground plane of wire or patch antennas for low profile design which is desirable in many wireless communications systems. [3].

The key aspect of the present work is: How effective are EBG structures for low profile antenna applications?

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Mushroom-style design is known to have effective bandgap for surface-wave propagation. It can be used to improve antenna radiation patterns. When the incident wave is a plane wave ($k_x{}^2 + k_y{}^2 \leq k_0{}^2$, k_z has a real value), the reflection phase of the EBG structures varies with frequency. At certain frequency the reflection phase is zero degree, which resembles the perfect magnetic conductor that does not exist in nature. [1]. In addition to this fractalization of antenna and EBG surface will additionally decrease the final dimensions of the antenna. Besides that, a multilayer metamaterial will optimize a little more the antenna size.

As previously stated, to figure out how the EBG improves the antenna parameters, a combination of fractal dipole antenna and EBG surface has been done. In this paper a Minkowski fractal [4]. has been used. In order to obtain maximum efficiency and compact dimensions fractalization of the antenna is restricted to the second iteration.

This paper focuses on mushroom-like EBG structures [3] invented by Sievenpiper et al. [5]. The structure studied here has a feature of compactness and can be integrated into printed circuit boards, which is very critical in handheld devices. As explained earlier, one of the key aspects is compact size of the antenna. For that reason, fractalization of the metamaterial surface is also needed. Once again the Minkowski fractal is chosen but in a concrete example a conventional algorithm has not sufficient outcome. The last statement imposed a different approach which requires our own algorithm for fractalization of the metamaterial surface.

II. Conception of the EBG Structure

As discussed above, for optimal dimensions a multilayer surface has been developed. Our suggestion is based on [1]. but the main difference from [1]. is fractalization of patches, which minimize significantly the overall dimensions. Additionally a second layer of the surface is deployed and it will plummet a little more the sizes of the structure. The cross section of the structure is displayed in Fig. 1.

From Fig. 1, it can be seen that the antenna consists of double sided dipole where up and down sides are connected with connecting vias. In this way losses in a dielectric substrate can be overcome. Besides that a bandwidth of the antenna can be increased. The first and the second layer of the EBG structure (upper and down layer respectively to Fig. 1) are connected each other with circuit board lacquer (red lines in

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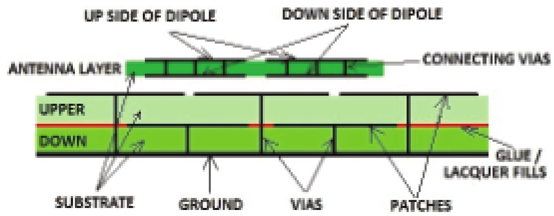

Fig. 1. Schematic diagram of the EBG structure.

Fig. 1) which almost all manufacturers used for manufacturing a multilayer PCB.

As mentioned above, fractalization is performed through modifying Minkowski algorithm. Instead of using the suggestions of Minkowski method [4]., which divides every side to three equal parts, our suggestion is one side to be divided into five. The reason for that is optimizing dimensions but at the same time, the capacitance does not have any abrupt changes. The classic algorithm and our suggestion are shown in Fig. 2.

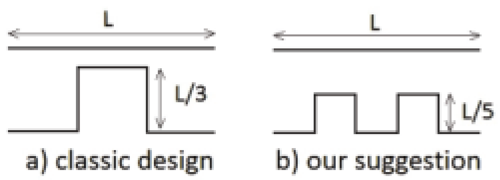

Fig. 2. Fractal algorithm of the EBG structure

The inductance in that model comes from the current flowing along adjacent patches and connecting vias. The capacitance result comes from the fringing electric field between adjacent metallic patches. The equivalent circuit model is able to predict the reflection phase as well as some surface wave properties. The capacitance and inductance in the equivalent circuit can be approximated by following formulas [6].

$$L = \mu_0 \mu_r h \tag{1}$$

$$C = \frac{w\epsilon_0(1+\epsilon_r)}{\pi} cosh^{-1}\left(\frac{w+g}{g}\right) \tag{2}$$

where h - height of the substrate; w - width of the patches; g - gaps between patches.

The fractional bandwidth (BW) ±90 ° of the reflection phase is received by the following formulas [6].

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{3}$$

$$BW = \frac{\Delta\omega}{\omega_0} = \frac{1}{Z_0}\sqrt{\frac{L}{C}} \tag{4}$$

Based on above equations initial calculations of structure are performed. The surface is optimized additionally with EM simulator where the final sizes are determined completely. The upper layer of multilayer design is displayed in Fig. 3

As mentioned above one of the driving factors in RFID systems is the manufacturing price. For this reason, a cost-effective FR-4 substrate is selected. The thickness of the substrate is 2mm for each layer and the gaps between patches are 0.45mm.

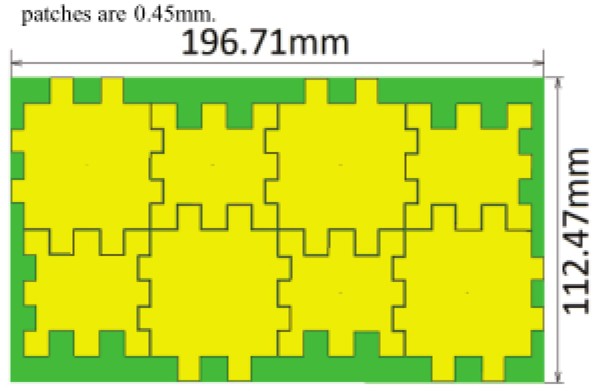

Fig. 3. Upper layer of the structure.

The second layer of the suggested metamaterial is illustrated in Fig.4.

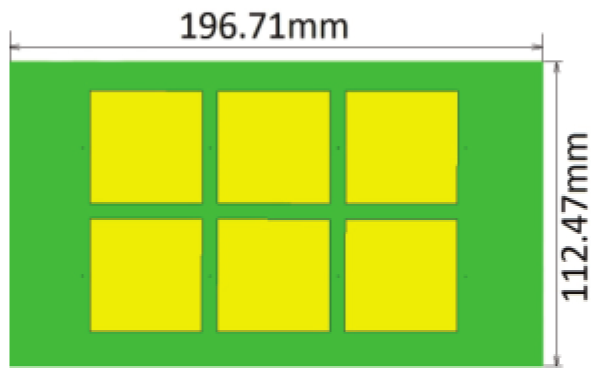

Fig. 4. Down layer of the structure.

As it can be seen from Fig. 4 this layer is not fractalized. The main disadvantage of this design is that the magnetic lines of vias from upper layer are dissipated in the conductive patches of the second layer (see cross section view in Fig.1). This leads to decrease of the inductance, which reduces the overall performance of the antenna, especially increases the resonant frequency and reduces the Q-factor of the resonant system. Despite these shortcomings, a simulation has been performed and the results concur with the above-mentioned assumptions.

On the other hand the simulation with bigger reflector has been conducted. It consisted of 4 x 4 elements, not 4 x 2 as the proposed design, shown in Fig.3. The idea is to estimate whether larger reflector will provide an extra gain. The simulated outcome was negative and therefore this concept is abolished. It is evident that the resonant elements which are far apart from radiators, collect less and have no significant influence on the overall antenna. Based on that the design with 4 x 2 is chosen.

With regard to previous section the radiating element is fractal dipole. It is optimized through Minkowski fractal method (as it described in [4].) to the second iteration because after this approximation there is no significant reduction in dimensions but it has a huge decrease in antenna efficiency.

For feeding the dipole antenna a U-shaped coax balun is used. Through using it, a very good compromise between efficiency and transformation (balanced to unbalanced line) can be achieved. Another possible solution is a SMD balun (1.5:1) to be adapted. The main disadvantages of this solution is higher insertion loss (approximately 0.5 dB) compared to the first suggestion. This is the main premise for choosing the first option.

The antenna layout is displayed in Fig. 5.

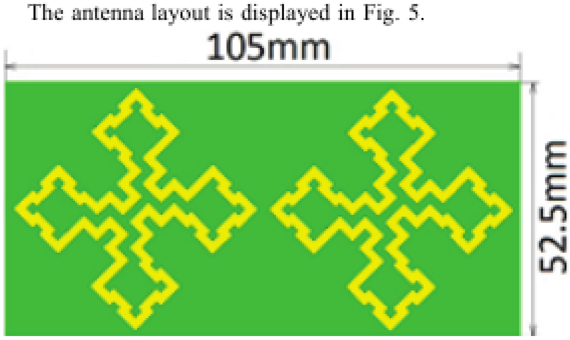

Fig. 5. Antenna layout

III. RESULTS FOR DIPOLE ANTENNA

In this section simulated results of the dipole antenna are presented. To do simulations commercial software HFSS is used. It has been performed three different simulations and the reason for that it is to understand which iteration would be the most practically useful. Classic dipole antenna has approximate gain 2.15 dB [1]. On the first iteration gain is 2.03 dB and dimensions of the antenna shrink 13 %. On the second iteration gain is 1.8 dB and sizes of the dipole decrease 20 % compared to the classic dipole design. On the third iteration gain is 1.37 dB and dimensions go down 22 % compared to the classic design. The antenna is printed on a FR-4 substrate with thickness 0.5mm which only has a feature to hold it because a dipole is duplicated on a back side and for a connection vias are employed. In Fig. 6 is shown the antenna pattern.

The input return loss is displayed in Fig. 7.

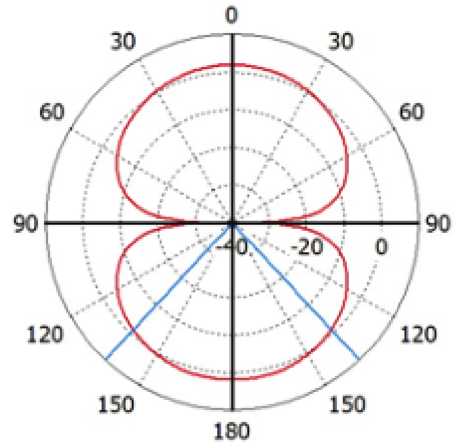

Fig. 6. Radiation pattern of the dipole antenna.

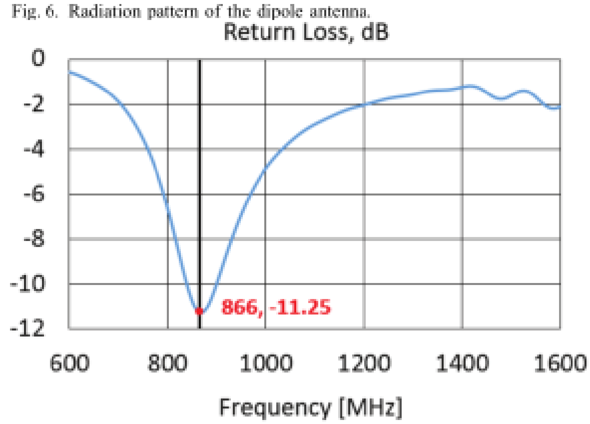

Fig. 7. Return loss of the dipole antenna.

IV. OUTCOMES FOR DIPOLE ANTENNA WITH EBG REFLECTOR

A driving reason for researching the low-profile (closed spaced reflector) antenna is the necessity of compact systems for handheld applications. To achieve high gain and low profile at the same time, a parametric analysis is performed. The results are shown in Table I.

From Table I it can be concluded that a reasonable compromise between high gain and low profile antenna can be achieved at 1 mm reflector distance from the radiating element. When the distance becomes over 15 mm the efficiency of the EBG surface significantly decreases. Construction is shown in Fig. 8. The overall dimensions of the antenna are 196.71 x 112.47 x 5.5mm. The dipole and reflector are connected with double sided adhesive tape which has 1 mm thickness.

Figure 9. shows the radiation pattern of the antenna with EBG structure. Also, Figure 9. shows gain of the antenna is G = 3, 47 dBi. The directivity is 6.93 dB. The main losses in our design come from high tanδ of FR-4 substrate. As mentioned earlier the main goal is a low price and consequently FR-4 is our choice.

TABLE I
PARAMETRIC ANALYSIS OF THE DISTANCE BETWEEN THE ANTENNA AND THE EBG STRUCTURE

distance [mm]	frequency 866 MHz; G = [dBi]
0.1	3.30
0.3	3.34
0.5	3.41
0.7	3.44
0.9	3.46
1	3.48
2	3.52
3	3.58
4	3.64
5	3.68
10	3.72
15	3.76
20	3.45
25	3.26
30	3.08
35	2.84
40	2.60
45	2.54
50	2.41

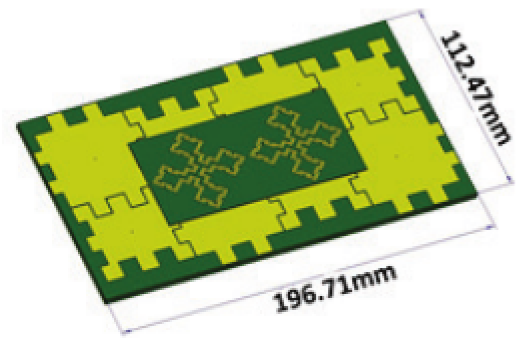

Fig. 8. Model of the antenna.

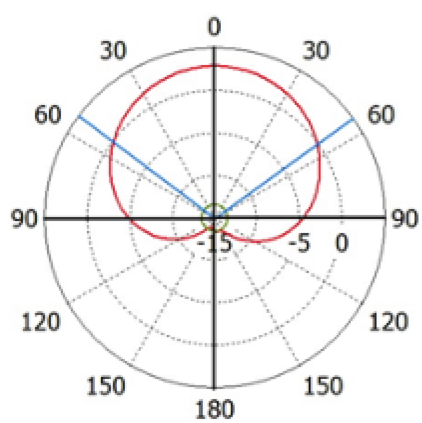

Fig. 9. Radiation pattern of the dipole antenna over EBG structure.

It is obvious that if bigger efficiency is needed RO4003C or other material with small tanδ is necessary to be used. The width of the main lobe is 107 ∘ which allows wide range to be scanned by the antenna. The return loss of the antenna is displayed in Fig. 10.

According to Fig. 10 the antenna has good impedance matching with reasonable bandwidth which makes antenna insensitive to manufacturing tolerances.

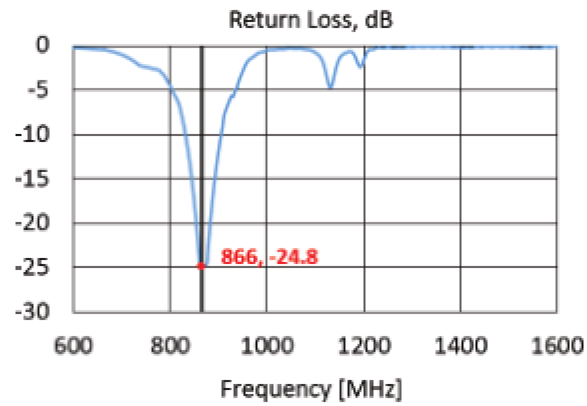

Fig. 10. Return loss of the dipole antenna over EBG structure.

V. CONCLUSION

This paper introduced possible design of dipole antenna with EBG surface. EBG surfaces are used to increase antenna gain and decrease the antenna thickness compared with traditional air gap antennas. All this features give the antenna possibility for mass production. It is intended mainly for RFID communications.

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REFERENCES

[1] F Yang and Y Rahmat-Sami, "Electromagnetic Band Gap Structures in Antenna Engineering", Cambrigde University Press, 2009
[2] T.H. Liu, W.X. Zhang, M. Zhang and K.F.Tsang, "Low profile spiral antenna with PBG substrate", Electron Lett., vol.36, no.9, 2000, pp. 779−780
[3] F. Yang and Y Rahmat-Sami, "Reflection Phase Characterizations of the EBG Ground Plane for Low Profile Wire Antenna Applications", IEEE Transactions on Antennas and Propagation, Vol. 51. №10, October 2003, 2691 - 2703 pages
[4] J.P. Gianvittorio, "Fractal Antennas: Design, Characterization, and Applications, University of California, 2000
[5] D. Sievenpiper, L. Zhang, R. F. J Broas, G. Alexopolus and E.Yablonovich "High-impedance electromagnetic surface with a forbidden frequency band", IEEE Trans. Microwave Theory Tech., vol. 47., November 1999, 2059 - 2074 pages
[6] T.T. Nguyen, D. Kim, S. Kim and J. Jang, "Design of a wide- band mushroom-like electromagnetic bandgap structure with magneto-dielectric substrate", ICITA, 2009