

Bandwidth Enhancement of PIFA with Novel EBG Ground

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Abstract—A Planar Inverted-F Antenna (PIFA) with novel compact double-layer Electromagnetic Band-Gap (EBG) structure is presented. The upper layer of the EBG structure is formed by an interdigital structure and a cross-slot is embedded in a metal patch as the lower layer. Compared with a conventional PIFA, the simulated -10dB impedance bandwidth of the proposed PIFA is broadened by 48% with similar directivity pattern characteristics. In order to verify the simulated analysis, antenna prototypes are fabricated. From the measured results, the bandwidth has been improved from 550MHz to 800MHz, which means an expansion of 45%. The measured results basically show agreement with the simulated results, which illustrates the superiority of this PIFA with the EBG ground plane.

I. INTRODUCTION

In recent years, more and more attention has been paid to the development of antennas with small size and wide bandwidth for mobile communication. Conventional planar inverted-F antennas (PIFA) have attracted so much attention as they have many advantages namely low cost, small size and low backward radiation, compared with conventional microstrip antennas [1]. However, they have limitations of low efficiency, narrow bandwidth and surface wave loss. A large amount of effort has been made to broaden its bandwidth, such as a T-shaped ground plane [2] and meandered shorting strip [3]. But these methods need to be further optimized. Another way to improve antenna performance is to use Electromagnetic Band-Gap (EBG) as the antenna's ground plane. EBG structures are periodic structures with the characteristic of high-impedance electromagnetic surfaces within a certain frequency band-gap [4]. A conventional PIFA do not function effectively when it is applied on perfect electric-conductor (PEC) ground plane. However, it works efficiently above a high-impedance surface. Because the high surface impedance is capable of prohibiting the propagation of electromagnetic waves [5] and has the characteristic of in-phase reflection [6]. This property can improve the overall performance of the antenna without changing the antenna's dimension.

However, practical applications of EBG structures have difficulties in accommodating their physical sizes, because the dimension of an EBG lattice has to be half of the free space wavelength. The study of a mushroom-like EBG structure changes this situation. The length of the periodic EBG unit approaches 10% of the wavelength. Compared with other EBG structures such as dielectric rods and holes, this structure has a superior feature of compactness [7]. In [8], a mushroom-like EBG structure is used as the ground plane of the PIFA, so that the original relative bandwidth is increased from 7.1% to 10%. However, if the layout of components is required to be very

compact, the mushroom-like EBG structure is still too large. In [9], a new JCSS (Jerusalem Cross) geometry is applied to the mushroom-like EBG structure. It greatly improves the bandwidth of the PIFA. However, because the frequency of band-gap generated by the EBG structure is high, the antenna's bandwidth only increases at 5GHz, while at 2.5GHz its bandwidth is even narrower than the conventional PIFA.

In this paper, in order to further extend the band-gap width and reduce the band-gap frequency, the concept of interdigital capacitor is introduced into the design of the mushroom-like EBG structure. The connection of two adjacent elements constructs an interdigital structure, which results a larger fringe capacitor [10], [11]. The design of a double-layer EBG structure [12] makes another step towards compact EBG configuration. In this structure, a metal patch is inserted between the upper patch of the EBG structure and the ground plane. The double-layer EBG structure increases the equivalent capacitance of EBG units by increasing the effective area of the EBG unit. A novel type of EBG structure is designed for much lower frequencies by combining the concept of interdigital capacitor with the design of a double-layer EBG structure. The PIFA by using this EBG structure as the antenna's ground plane is proposed and analyzed using Ansoft HFSS. The simulation and measurement results reveal that the novel EBG structure can significantly improve the antenna's performance. The proposed PIFA has a similar radiation pattern shape but the bandwidth is extended by 48% at 3.2GHz, compared with a conventional PIFA of the same size.

II. ELECTROMAGNETIC BAND-GAP STRUCTURE DESIGN

Within the EBG structure, the resonance effect of the periodical unit plays a leading role when the band-gap is formed. The inductance L results from the current flowing through the connecting via. The gap between the conductor edges of two adjacent cells introduces equivalent capacitance C . Thus a two dimensional periodic LC network is realized which results in the frequency band-gap and the center frequency of the band-gap. The central frequency of the band-gap (f_0) is approximately determined by the unit's equivalent inductance (L) and equivalent capacitance (C):

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

As (1) shows, in order to achieve an even more compact EBG structure, the equivalent capacitance and inductance should be increased. But in the EBG design procedure, if the dielectric material and its thickness have been chosen, the inductance cannot be altered. Therefore, only the capacitance can be enlarged. According to the analysis above, a new planar EBG structure is proposed. As is shown in Figure 1(a) and (b), it is a double-layer EBG structure. The upper layer is formed by an interdigital structure, whose branches crosses over with each other and constructs an interdigital capacitor. The length of the interdigital structure is 2.1mm, the width is 0.2mm and the distance between two interdigital units is 0.6mm. An interdigital EBG structure is connected with the ground plane by a metal via hole with the radius of 0.5mm. This interdigital structure greatly increases the coupling path of two units so it can realize a larger capacitance. The design of a double-layer EBG structure is another improvement in this paper. As is shown in Figure 1(c), a metal patch is inserted between the upper patch of the EBG structure and the ground patch. To avoid its contact with the metal via hole, there is a via hole on the metal patch, with the radius of 1.4mm. At the same time, to increase the coupling capacitance, another cross slot whose width is 0.7mm is added to the metal patch. The spaces between the upper EBG structure and the metal patch, the metal patch and the ground plane are all filled with FR4 substrate whose relative permittivity is 4.4. Both of the two substrate boards have a thickness of 1mm.

In the array of the EBG structure, as is shown in Figure 1 (d), the metal patches under adjacent interdigital EBG units connect with each other. In this way, the coupling capacitance between two adjacent EBG units can be increased and the resonant frequency is further lowered. Thus, the EBG structure can be miniaturized and used in low-frequency PIFA.

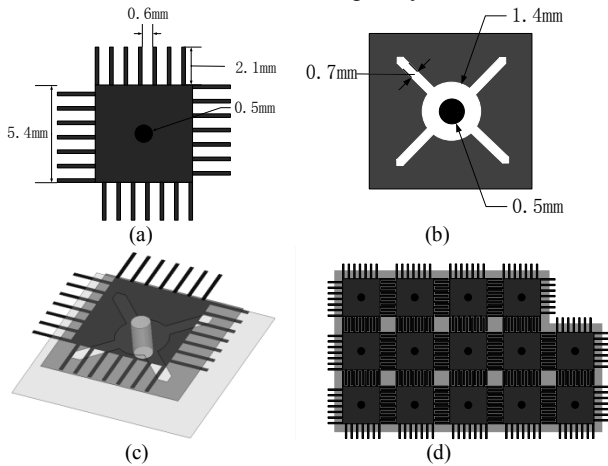


Figure 1. The view of the proposed EBG: (a)The upper layer of interdigital EBG structure (b)The metal patch inserted in the EBG structure (c)The EBG unit cell (d)The array of the EBG structure.

III. PIFA WITH EBG GROUND PLANE

The configurations of the PIFA with the EBG ground plane are shown in Figure 2 and 3. The ground of the proposed antenna is composed of two parts. The first part is a new EBG structure (45mm×25mm) of 14 unit cells. These periodic cells are printed on a dielectric slab with permittivity of 4.4 and a thickness of 2mm. The second part is a dielectric slab (45mm×60mm) with permittivity of 4.4 and a thickness of 2mm. The radiation patch (18mm×10mm) is placed above the ground with a height of 8.5 mm. The proposed antenna is fed by 50Ω coaxial probe feeding structure underneath the ground plane. The frequency of operation (f_r) is calculated using (2), where c is the velocity of light (a constant approximately equal to 3×10^8 m/s), A and B are, respectively, the width and the length of the radiating patch. The dimension of the radiating patch:

$$f_r = \frac{c}{4(A+B)} \quad (2)$$

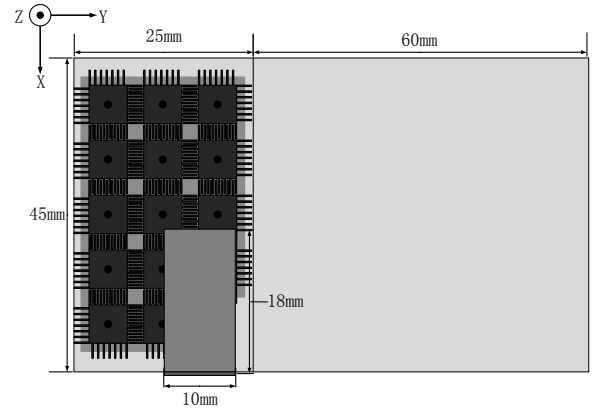


Figure 2. The top view of the PIFA with the EBG ground plane metal via hole

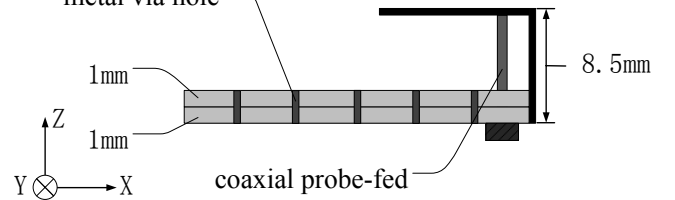


Figure 3. The side view of the PIFA with the EBG ground plane

IV. ANALYSIS OF SIMULATION AND MEASUREMENT

For comparison, a conventional PIFA is also constructed with a radiating patch of 18mm×10mm. A short-circuit probe and a coaxial probe is placed on the ground plane (45mm×85mm×2mm) with a height of 8.5mm. The simulated return losses of both the proposed antenna and the conventional PIFA with the same dimension are shown in Figure 4. The

simulated frequency range of the conventional PIFA for the return loss ≤ -10 dB ($VSWR \leq 2$) is from 3GHz to 3.43GHz with the bandwidth of about 430MHz at the centre frequency of 3.2GHz. The simulated frequency range of the PIFA with the EBG ground plane is from 2.94GHz to 3.58GHz with the bandwidth of about 640MHz at the same centre frequency. From the results, the bandwidth has been improved from 430MHz to 640MHz, which means an expansion of 48%. That is because the EBG structure makes the ground plane of PIFA as a high-impedance surface which leads to a change in the input impedance of the proposed antenna.

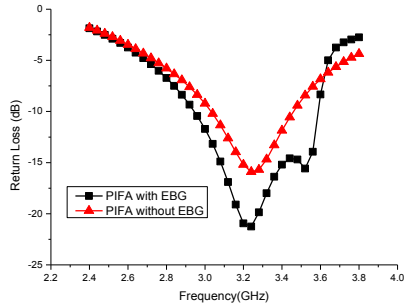


Figure 4. The simulated return losses of the PIFA with the EBG ground plane and the conventional PIFA

In order to verify the theoretical analysis of the antenna, according to the specific dimensions referred before, an antenna prototype is fabricated. As shown in Figure 5, a dielectric slab with permittivity of 4.4 is used, the radiating patch and a short-circuiting piece is made by copper with the thickness of 0.5mm. The antenna is fed by SMA connector coaxial. Here the return loss is measured by Agilent vector network analyzer and the results are shown in Figure 6.

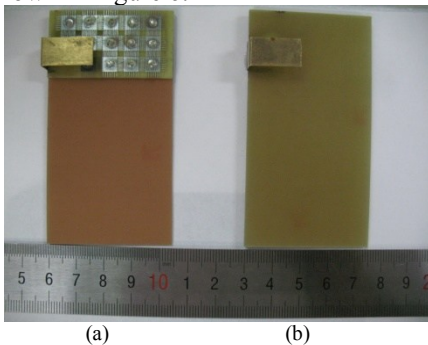


Figure 5. The prototypes (a) The PIFA with the EBG ground plane (b) the conventional PIFA

In Figure 6, the measured frequency range of the conventional PIFA for the return loss ≤ -10 dB ($VSWR \leq 2$) is from 3.1GHz to 3.65GHz with the bandwidth of about 550MHz at the centre frequency of 3.35GHz. The proposed antenna which is fabricated in the same size has a bandwidth as large as

800MHz from 3.05 to 3.85GHz at the same center frequency. Compared with the conventional PIFA, the bandwidth of the proposed antenna is expanded by 45%. The measured results basically show agreement with the simulated results, which illustrates the superiority of this PIFA with the EBG ground plane. But the measured frequency is lower than the simulated one. The discrepancy is mainly brought by the fabrication tolerance, because the resonance of the EBG is very sensitive to the dimension. Another reason is the measured errors in the experiment.

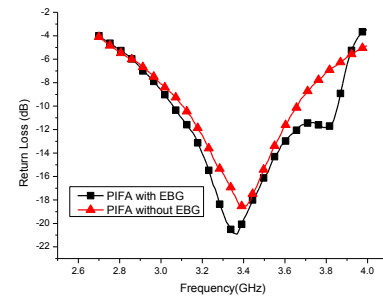


Figure 6. The measured return losses of the PIFA with the EBG ground plane and the conventional PIFA

The simulated far-field radiation pattern of the conventional PIFA and the proposed PIFA with the EBG ground plane at 3.35GHz and 3.6GHz are given in Figure 7. The shape of the pattern for the proposed PIFA is similar to that of the conventional PIFA. The simulated maximum radiation gain of the proposed PIFA and a conventional PIFA is 4.56dB, 4.41dB at 3.35GHz, and 4.81dB, 4.48dB at 3.6GHz, respectively. So it can be applied to the ground plane to expand bandwidth while maintaining a similar radiation pattern with the conventional PIFA.

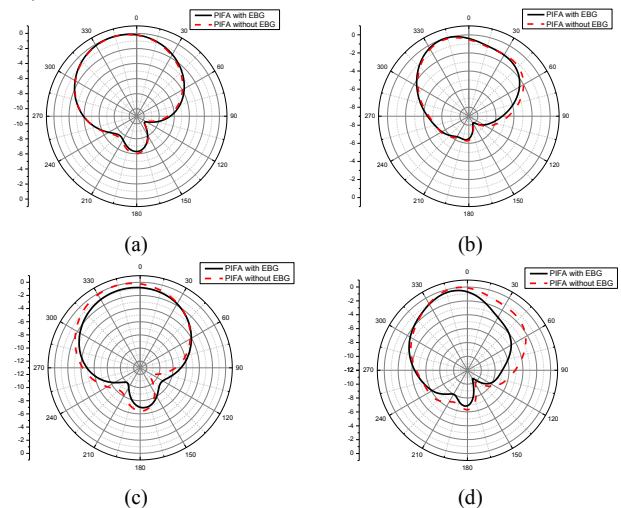


Figure 7. The normalized far-field radiation patterns of the PIFA with the EBG ground plane and the conventional PIFA. (a) the xz-plane of 3.35GHz, (b) the yz-plane of 3.35GHz, (c) the xz-plane of 3.6GHz, (d) the yz-plane of 3.6GHz

V. CONCLUSION

For application, a novel compact double-layer EBG structure in interdigital shape is investigated. Using the idea of the high-impedance surface to construct the ground plane, a novel type of compact PIFA is proposed. Compared with a conventional PIFA of the same size, the measured and the simulated results show that the EBG structure can significantly improve the patch antenna's bandwidth and the two antennas have similar directivity pattern characteristics. So the proposed antenna demonstrated with the new EBG structure is suitable for mobile-communication application.

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