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MINIATURE ELECTROMAGNETIC BAND-GAP STRUCTURE USING SPIRAL GROUND PLANE

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Abstract—An important application of electromagnetic band-gap (EBG) structures is reducing the mutual coupling and eliminating the scan blindness for array antennas. However, some array antennas have small element spacing, and traditional mushroom-like EBG materials are too large. Under this condition, miniature EBG structures are desired for these array antennas. In this paper, a novel method using spiral ground plane is proposed to reduce EBG structure sizes. A low frequency band-gap can be obtained by adjusting the width and length of the spiral arms. An experimental prototype is fabricated to validate the analysis. The measurement results show a good agreement with the simulation data. Compared with traditional mushroom-like EBG structures, the proposed EBG achieves more than 77% size diminution.

1. INTRODUCTION

In recent years, electromagnetic band-gap (EBG) structures have attracted a great deal of attention due to their interesting characteristics such as surface wave suppression and in-phase reflection. As an important application in array antennas design, EBG structures can reduce mutual coupling, improve array efficiency and eliminate scan blindness [1–3]. However, in some array antennas design process, the element spacing is too small to place traditional EBG materials. Miniature EBG structures are desired for these array antennas, which have gained broad attention from EBG researchers. Most previous works are changing EBG patches such as complementary geometries, spiral shape structures, and Hilbert curve [4–8].

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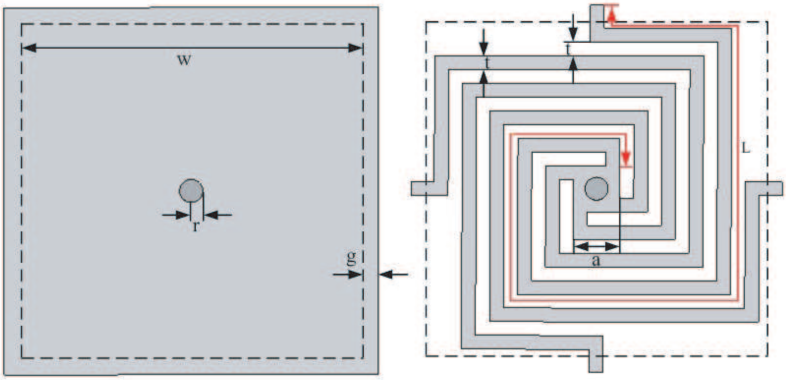
In this paper, a novel method of reducing EBG sizes is proposed by using spiral EBG ground plane. The spiral ground EBG structure consists of a square metal patch, a four-arm spiral ground plane, a dielectric substrate and a connecting metal rod. The equivalent LC model is analyzed, and the spiral ground plane can greatly enhance the equivalent inductance. Comparing it with traditional mushroom-like EBG structures, we can find that the proposed EBG structure can provide a lower frequency band-gap. In order to better understand the influence of the spiral ground plane on the stopband, a detailed parameter analysis is offered. An experimental prototype is fabricated and measured. The measured results show that the designed EBG material provides a frequency band-gap from 2.01 GHz to 3.07 GHz. Compared with the traditional mushroom-like EBG structure ($w = 0.12\lambda_{2.5G}$, $g = 0.02\lambda_{2.5G}$, $h = 0.04\lambda_{2.5G}$, $\varepsilon_r = 2.2$, $r = 0.005\lambda_{2.5G}$) [9], the proposed EBG achieves more than 77% size diminution.

2. SPIRAL GROUND EBG STRUCTURE

The traditional mushroom-like EBG structure and the proposed spiral ground EBG structure are shown in Fig. 1. The dashed line is a EBG patch, and the traditional EBG ground plane is replaced by a four-arm spiral ground plane. The two type EBG structures are etched on the dielectric substrate with a thickness of 1.6 mm and a relative dielectric constant of 2.65. The detailed parameters are exhibited in



(a) (b)

Figure 1. (a) Traditional mushroom-like EBG structure, (b) proposed spiral ground EBG structure. ($w = 7$ mm, $g = 1$ mm, $r = 0.25$ mm, $a = 1$ mm, $t = 0.3$ mm, $L = 18.65$ mm).

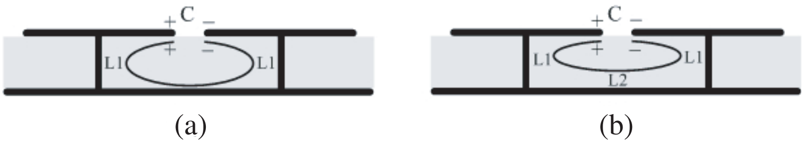


Figure 2. Equivalent LC models for the EBG structures. (a) Traditional mushroom-like EBG structure, (b) proposed spiral ground EBG structure.

Fig. 1. The equivalent LC models are shown in Fig. 2. The inductance L_1 of the traditional mushroom-like EBG structure is provided by the connecting rods, which is determined by the thickness of the substrate, permeability, and radius of the rods. The proposed spiral ground plane can provide an extra inductance of L_2. The inductance L_2 increases with reducing the spiral-arm width of t or increasing the spiral-arm length of L. The resonant frequency of the proposed spiral ground EBG structure is calculated as following:

$$f_0 = \frac{1}{2\pi\sqrt{(2 * L_1 + L_2)C}} \tag{1}$$

As shown in formula (1), we can reduce the resonant frequency by increasing the inductance L_2.

3. BAND-GAP CHARACTERISTICS OF THE SPIRAL GROUND EBG STRUCTURE

3.1. Numerical Simulation

An FDTD/PBC algorithm is used to analyze the EBG structures [10]. Fig. 3 provides the FDTD/PBC computation model of a EBG unit for surface wave band-gap characterization. A single EBG unit is surrounded by periodic boundary conditions (PBC) in the horizontal directions and perfectly matched layers (PML) along z-axis. The FDTD simulated dispersion diagrams for the traditional mushroom-like EBG structure and the proposed EBG structure are shown in Fig. 4. A frequency band-gap between the first and second modes in the two simulated dispersion diagrams can be clearly observed. For the traditional mushroom-like EBG structure in Fig. 4(a), a frequency band-gap is obtained between 5.15 GHz and 7.21 GHz. While for the spiral ground EBG structure in Fig. 4(b), there is a lower frequency band-gap from 1.95 GHz to 2.81 GHz. By comparing Fig. 4(a) with (b), we can see that the spiral ground plane greatly reduces the frequency band-gap.

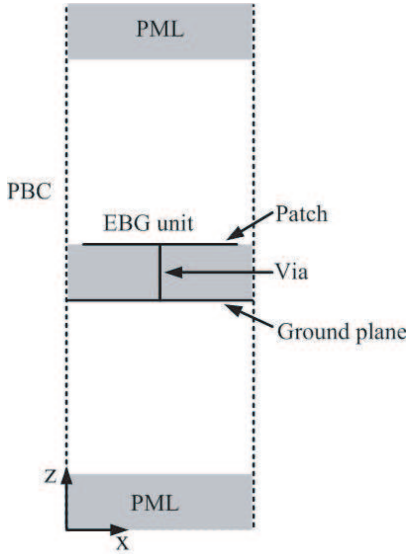


Figure 3. FDTD/PBC model of a EBG unit for surface wave band-gap characterization.

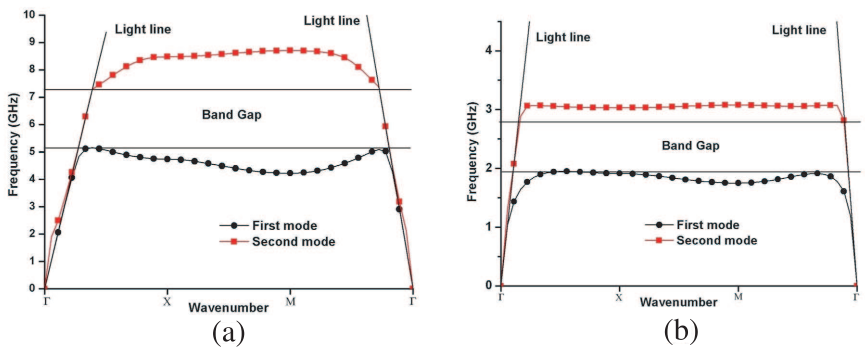


Figure 4. FDTD simulated dispersion diagrams for the EBG structures. (a) Traditional mushroom-like EBG structure, (b) proposed spiral ground EBG structure.

3.2. Parameter Analysis of the Spiral Ground EBG Structure

The spiral ground plane of the proposed EBG structure plays a key role in reducing the frequency band-gap. It is necessary to analyze the parameters of the spiral ground plane in detail. The spiral-arm length

L will increase with the reduction of the spiral-arm width t. The spiral ground EBG structures with different spiral-arm widths and lengths are simulated, and the results are plotted in Fig. 5. When the spiral-arm width $t = 0.4\,\mathrm{mm}$ and length of $L = 15.2\,\mathrm{mm}$, a frequency band-gap from 2.29 GHz to 3.16 GHz can be obtained. When the spiral-arm width $t = 0.3\,\mathrm{mm}$ and length $L = 18.65\,\mathrm{mm}$, the frequency band-gap is from 1.95 GHz to 2.81 GHz. While the spiral-arm width $t = 0.2\,\mathrm{mm}$ and length $L = 31.9\,\mathrm{mm}$, there is a lower frequency band-gap which is from 1.28 GHz to 1.65 GHz. From the three simulated results, we can find that the frequency band-gap reduces with the reduction of the spiral-arm width and the increase of the spiral-arm length.

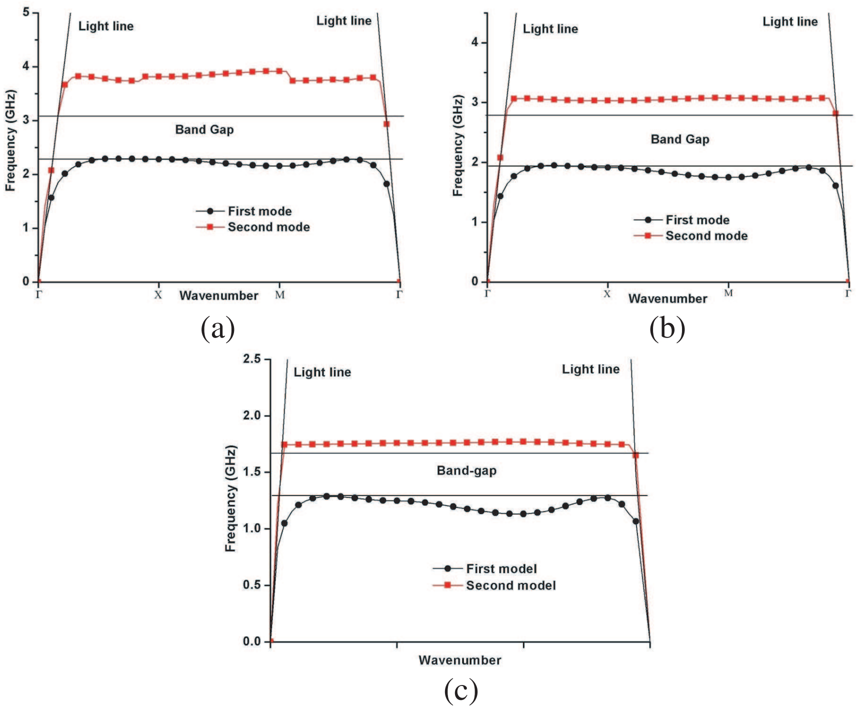


Figure 5. FDTD simulated dispersion diagrams for different spiral-arm width t and length L. (a) $t = 0.4\,\mathrm{mm}$, $L = 15.2\,\mathrm{mm}$, (b) $t = 0.3\,\mathrm{mm}$, $L = 18.65\,\mathrm{mm}$, (c) $t = 0.2\,\mathrm{mm}$, $L = 31.9\,\mathrm{mm}$.

4. EXPERIMENTAL RESULTS

The two type EBG structures are fabricated and shown in Fig. 6. Figs. 6(a) and (b) are the top and bottom of the traditional mushroom-like EBG structure. Figs. 6(c) and (d) show the top and bottom of the spiral ground EBG structure. The transmission coefficients are measured by using a couple of coaxial probe [11]. The measured transmission coefficients of the TM surface wave are shown in Fig. 7. The traditional mushroom-like EBG structure has a frequency bang-gap from 5.60 to 7.67 GHz, and the band-gap of the proposed spiral ground EBG structure spans the frequency range from 2.01 to 3.07 GHz. Compared with the traditional mushroom-like EBG structure ($w = 0.12\lambda_{2.5G}$, $g = 0.02\lambda_{2.5G}$, $h = 0.04\lambda_{2.5G}$, $\varepsilon_r = 2.2$, $r = 0.005\lambda_{2.5G}$), the proposed spiral ground EBG achieves more than 77% size diminution.

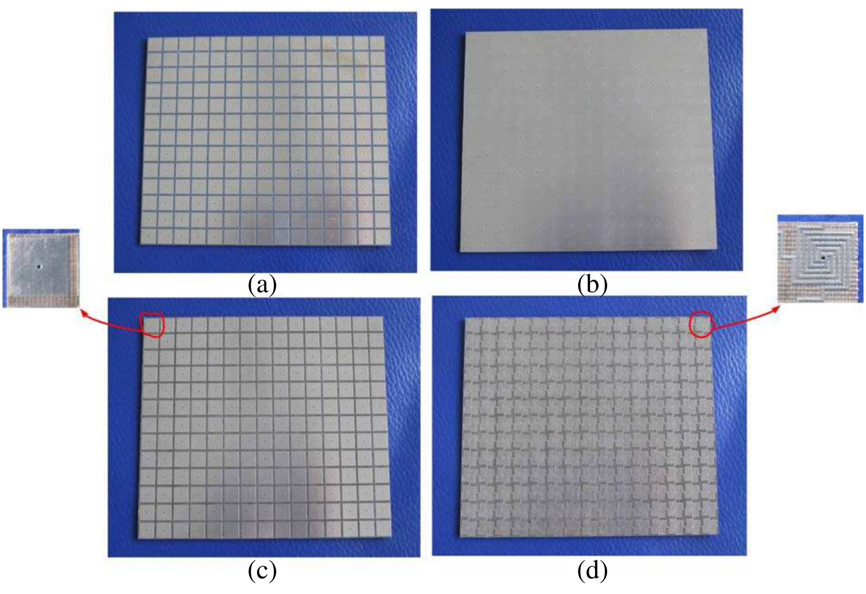
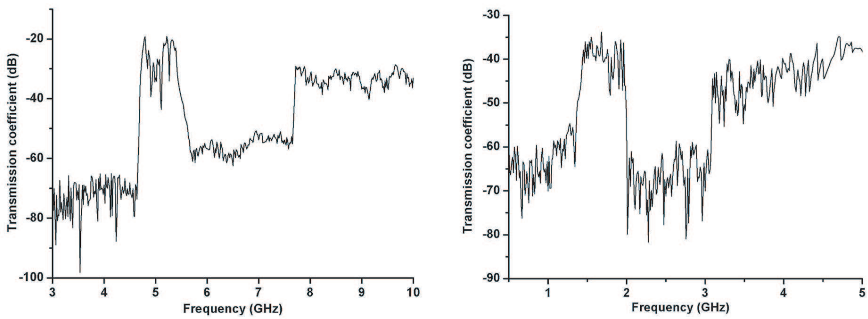


Figure 6. Photos of the fabricated EBG. (a) Top of the traditional mushroom-like EBG structure, (b) bottom of the traditional mushroom-like EBG structure, (c) top of the proposed spiral ground EBG structure, (d) bottom of the proposed spiral ground EBG structure.



(a) (b)

Figure 7. Measured transmission coefficients of the TM surface wave for the EBG structures. (a) Traditional mushroom-like EBG structure, (b) proposed spiral ground EBG structure.

5. CONCLUSION

In this paper, a novel method of reducing EBG sizes is proposed by using spiral EBG ground plane. The simulated and experimental results show that the proposed method can effectively reduce EBG sizes. The equivalent LC models are provided, and the spiral ground plane can greatly enhance the equivalent inductance. The frequency band-gap reduces with the reduction of the spiral-arm width or the increase of the spiral-arm length. Compared with traditional mushroom-like EBG structures, the proposed EBG structure achieves more than 77% size diminution.

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