

Design of Three-layer Circular Mushroom-like EBG Structures

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Abstract— In this paper two types of three-layer mushroom-like electromagnetic band-gap (EBG) surfaces with circular patches are investigated. One of them consists of a square array of circular patches and the other one consists of a triangular array of circular patches in upper and lower layers. Guidelines for designing a ground plane for low profile antenna applications are presented using the reflection phase characteristics. The effect of some parameters of the three-layer structures on the reflection phase characteristic is studied. The frequency band in which a wire antenna adjacent to the three-layer EBG surface has good matching is determined by investigating the reflection phase characteristics of the EBG ground plane.

1. INTRODUCTION

In recent years, unique properties of electromagnetic band-gap (EBG) structures have made them applicable in many antenna and microwave applications. Two main interesting features associated with EBG structures are suppression of surface waves and in-phase reflection coefficient for plane waves [1–3]. Suppression of surface waves results in higher efficiency, smoother radiation pattern, and less back lobe and side lobe levels in antenna applications [1, 2]. On the other hand, these structures can be used in design of low profile antennas because the radiating current can lie directly adjacent to the ground plane without being shorted [1, 3].

The main reason for using three-layer EBG surfaces is to obtain lower zero-reflection phase frequency in comparison with two-layer structures. This can be shown by computing the reflection phase of the structure when a normal incident plane wave is illuminated to the surface. The relation between the reflection phase characteristic of an EBG surface and the input-match frequency band of a wire antenna placed above the surface is investigated in [3]. It is shown that the frequency region where the EBG surface has a reflection phase between 45° and 135° is very close to the input-match frequency band of the low profile wire antenna which is placed directly adjacent to the surface. Therefore, one can use the reflection phase curve to identify the input-match frequency band of the antenna. Reflection phase of a periodic surface can be computed using one unit cell of the structure with periodic boundary condition as described in [4].

In this paper we show that a three-layer EBG surface has significantly lower zero-reflection phase frequency comparing to a two-layer structure and then we investigate the effect of the three-layer structures parameters on the reflection phase characteristic. By means of these curves, design guidelines for a three-layer circular mushroom-like EBG ground plane are obtained. Finally, three different configurations for three-layer EBG structures compared based on their reflection phase characteristics.

2. THREE-LAYER CIRCULAR MUSHROOM-LIKE EBG SURFACES

Figure 1 depicts two types of three-layer circular mushroom-like EBG surfaces. Patches radius in the upper and lower layers are r_t and r_b , respectively. In this investigation, the radius of circular patches in both layers have the same values ($r_t = r_b$) and the gap size is represented by g . In Fig. 1(a) the circular patches in both layers are located in a square array while in Fig. 1(b) a triangular array of circular patches forms a three-layer EBG surface. The dielectric constants of the upper and lower substrates are indicated by ϵ_{r1} and ϵ_{r2} , respectively. The thicknesses of upper and lower substrates are t and h .

The reflection phase of an EBG surface when a normal incident plane wave illuminates to the surface is investigated. Here, three cases are considered. First, the reflection phase of a two-layer

Table 1: The parameters in design of two- and three-layer EBG structures.

t	h	ϵ_{r1}	ϵ_{r2}	$r_t = r_b = r$	g
0.1 mm	3 mm	3.25	4.4	4 mm	0.5 mm

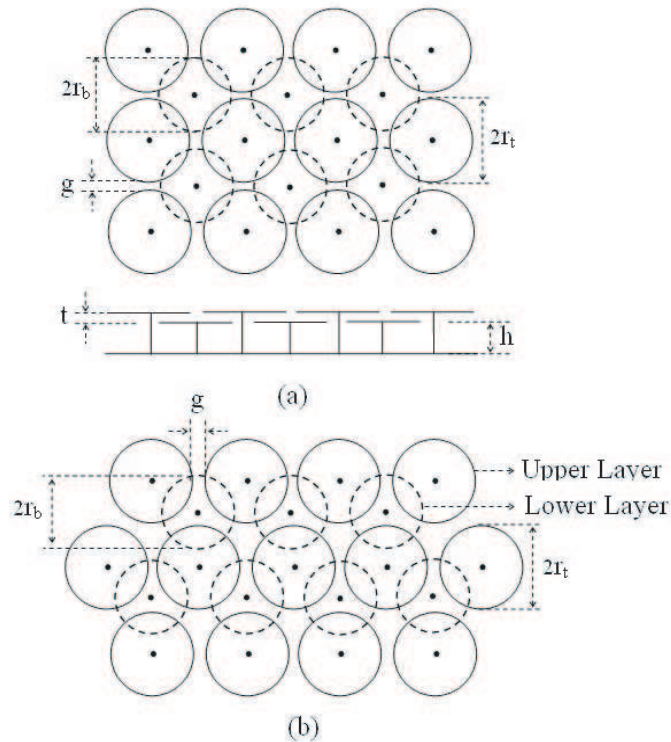


Figure 1: Three-layer mushroom-like EBG surfaces: (a) Square array of circular patches, (b) Triangular array of circular patches.

circular EBG surface is computed and illustrated in Fig. 2(a). Circular patches with radius of r are just printed on the upper layer and the height of patches from the ground plane is $t + h$. The values of parameters for this design are shown in Table 1. The reflection phase characteristics of three-layer EBG surfaces shown in Fig. 1 are illustrated in Fig. 2(b). For both configurations of three-layer EBG structures the radius of circular patches in both layers are the same as the radius of patches in two-layer structure, i.e., r . As can be seen, the zero-reflection phase frequencies of both three-layer structures are significantly lower than that of the two-layer structure. Also, the EBG structure with triangular array of circular patches has lower zero-reflection phase frequency comparing to the EBG structure with square array of circular patches.

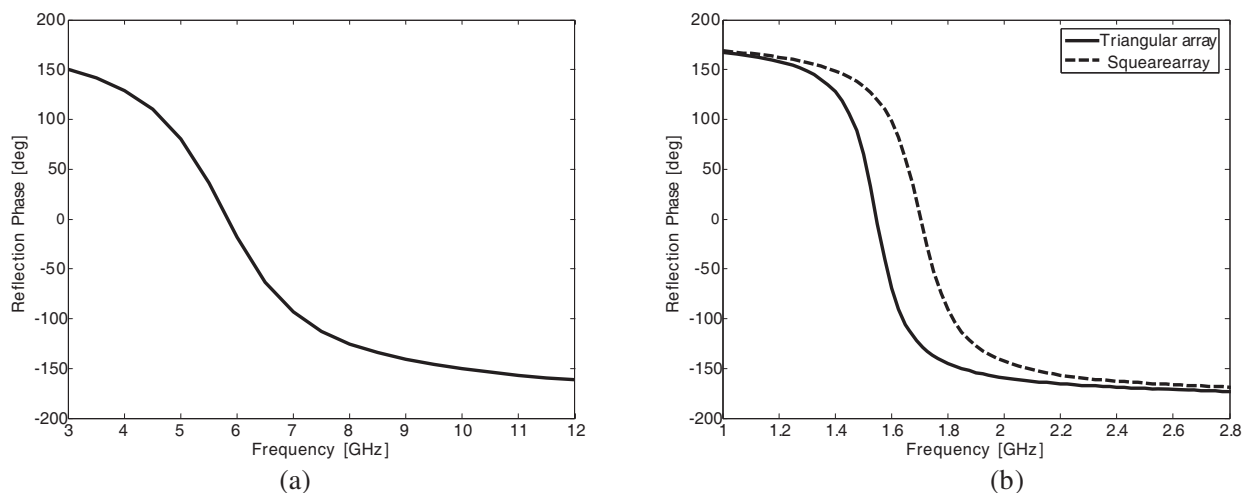


Figure 2: (a) Reflection phase characteristic of a two-layer EBG surface, (b) Reflection phase characteristics of three-layer EBG surfaces.

3. PARAMETRIC STUDY

Effects of various parameters in a two-layer EBG surface on the reflection phase characteristic when a normal incident plane wave illuminates to the surface have been previously studied [3]. Studies on three-layer EBG structures show that, when the dielectric constant or thickness of the lower layer increases the zero-reflection phase frequency would decrease. This behavior can be seen in two-layer structures. Also, when the radius of patches increases or when the gap size decreases, zero-reflection phase frequency of the structure reduces. This is, also, similar to the behavior of

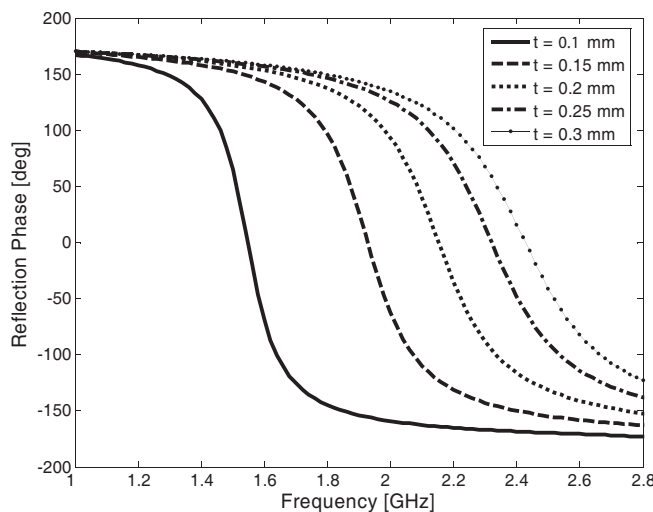


Figure 3: Effect of the upper layer thickness on the reflection phase characteristic.

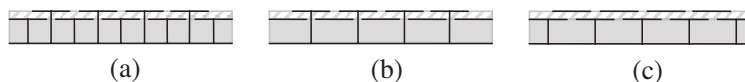


Figure 4: EBG surfaces with three different configurations.

two-layer EBG structures. In a triangular array three-layer structure, the effect of the upper layer thickness on the reflection phase characteristic is shown in Fig. 3. This parameter can noticeably change the zero-reflection phase frequency of the structure. As mentioned before, the frequency region where the EBG surface has a reflection phase between 45° and 135° is very close to the input-match frequency band of the low profile wire antenna using the surface as a ground plane. Therefore, to design an EBG surface as a ground plane for an antenna with a specific input-match frequency band, one should consider the reflection phase characteristics of the structure.

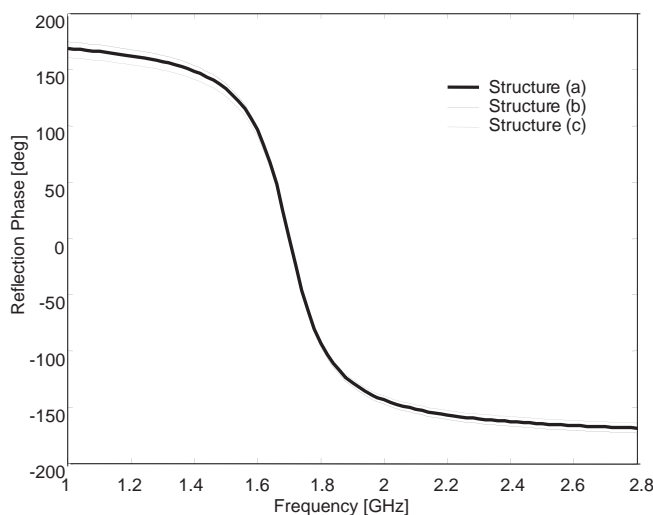


Figure 5: The reflection phase characteristics of EBG surfaces in Fig. 4.

4. THREE CONFIGURATIONS FOR THREE-LAYER EBG SURFACES

Implementation of vias in an EBG structure is not an easy process and reduction in the number of them can decrease the total cost of manufacturing. In Fig. 4 three different configurations for a three-layer EBG structure are illustrated. The number of vias in configurations (b) or (c) is reduced by a factor of two in comparison with the configuration (a). As illustrated in Fig. 5, the reflection phase characteristics of the three structures are similar. Therefore, any of the two configurations (b) or (c) can be used instead of the configuration (a). Although, there are some differences between the three configurations when the band-gap of the structure is considered.

5. CONCLUSIONS

Two low frequency three-layer EBG structures are introduced in this paper and compared with a two-layer EBG structure. One consists of a square array of circular patches in both upper and lower layers. The other one is formed by a triangular array of circular patches. It is shown that both of them have significantly lower zero-reflection phase frequency comparing to a two-layer structure. Also, it is shown that the triangular array structure has lower zero-reflection phase frequency with respect to the square array structure. Parametric study of a three layer structure is presented. Also, two different configurations of the EBG surface for reducing the number of vias are introduced.

REFERENCES

1. Engheta, N. and R. W. Ziolkowski, *Metamaterials Physics and Engineering Explorations*, Wiley, New York, 2006.
2. Sievenpiper, D., L. Zhang, R. F. J. Broas, N. G. Alexopolus, and E. Yablonovitch, "High-impedance electromagnetic surfaces with a forbidden frequency band," *IEEE Trans. Microwave Theory Tech.*, Vol. 47, 2059–2074, Nov. 1999.
3. Yang, F. and Y. Rahmat-Samii, "Reflection phase characterizations of the EBG ground plane for low profile wire antenna applications," *IEEE Trans. Antennas Propag.*, Vol. 51, 2691–2703, Oct. 2003.
4. Remski, R., "Analysis of PBG surfaces using Ansoft HFSS," *Microwave J.*, Vol. 43, No. 9, 190–198, Sept. 2000.