Patch Antenna Enhancement using a Mushroom-like EBG Structures

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***Abstract*—The mushroom-like EBG structure is used to suppress the surface waves excited by a patch antenna while improving its gain. The frequency band gap characteristics of the mushroom-like EBG was first determined with the aid of the dispersion diagram. A clear band gap was observed and the dimensions were tweaked to cover 2.4 GHz. It was found in order to effectively suppress the surface waves, a minimum of 3 columns of mushroom-like EBG is required to surround the patch antenna. Different configurations for the placement of the mushroom-like EBGs around the patch were also examined in order to minimize the overall size of the antenna. It is shown in the final design that the periodic structure can effectively increase the directivity and gain of the antenna.**

I. INTRODUCTION

One of the problems associated with the microstrip antenna is the excitation of surface waves. The energy trapped by these electromagnetic waves can be more than what is radiated into the air. On a finite ground plane, the surface waves that are scattered off the edges can lead to an increase in the back lobe radiation, gain deterioration and ripples in radiation pattern. [1]. This problem is further exacerbated by the use of thicker substrates and higher permittivity dielectrics. By suppressing the surface waves on the ground plane of the antenna, the back and side lobe levels can be reduced, therefore enhancing the energy in the broadside direction. This will increase the antenna's directivity and gain. One of the approaches for surface wave suppression is to surround the patch antenna with EBG structures [2]-[3].

In this paper, the effects of the mushroom-like EBG on a patch antenna are investigated. The EBG structure is designed such that its band gap covers the antenna's resonant frequency, thus inhibiting the propagation of surface waves excited by the antenna. By varying the number and location of the EBG structures, the overall size of the antenna can be reduced and the performance of the antenna can be improved.

II. PROCESS AND ANALYSIS

A. Design of Mushroom-like EBG Structure

The mushroom-like EBG structure is a 2-D EBG surface that consists of a metallic patch and a via that connects the patch to the ground as shown in Fig. 1(a).

The operating mechanism of the structure can be explained using an effective medium model with equivalent lumped LC elements. The shorting vias have an equivalent inductive effect while the gaps between the patches have an equivalent capacitive effect as shown in Fig. 1(b). At its resonant frequency, the impedance is very high and the structure impedes any surface waves, resulting in a frequency band gap [4]. For a substrate with fixed height and permittivity, increasing the patch width, W, or reducing the gap, g, leads to a decrease in the resonant frequency of the structure due to the rise in capacitance.

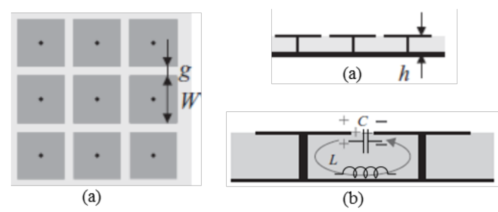

Figure 1. Mushroom-like EBG

To determine the frequency band gap, the dispersion diagram of an unit cell of the mushroom structure was plotted using the CST Microwave Studio. The band gap of the EBG structure was adjusted by tuning W and g to cover the frequency of 2.4 GHz. Fig. 2 shows the dispersion diagram of the designed mushroom EBG with W = 15 mm, g = 1 mm and via diameter of 1 mm on a FR-4 substrate of height 1.6 mm, relative permittivity of 4.5 and loss tangent of 0.025. As shown in Fig. 2, the band gap is from 2.2 GHz to 3.8 GHz.

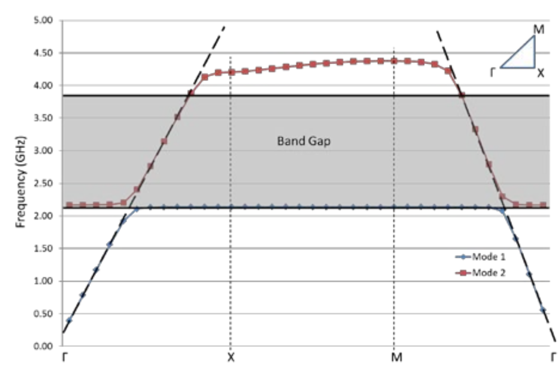

Figure 2. Dispersion diagram of designed EBG structure

B. Implementation of Mushroom-like EBG on Patch Antenna

A conventional patch antenna with inset feed was designed on the FR-4 substrate mentioned. The dimensions of the patch are 28.7 mm by 37 mm. The feed has length of 10.64 mm from the edge and a notch width of 0.6 mm. The width of the microstrip line is 3mm.

The number of columns of mushroom EBG structures placed around the patch antenna was varied to determine the number of columns required to effectively suppress the surface waves. The EBG structures were placed at least one period away from the edges of the patch antenna. The configuration of the mushroom EBG patch antenna is shown in Fig. 3(a). Simulations were done for different number of EBG columns. The original antenna of the same ground size (in brackets) is also simulated for comparison purposes. The simulation results are tabulated in Table I. It is seen that surrounding the antenna with 3 columns as shown in Fig. 3(a) exhibited noticeable improvements in terms of directivity and gain of the antenna.

TABLE I. COLUMNS OF EBG ON ANTENNA'S PERFORMANCE.

Columns of EBG	Resonant Frequency (GHz)	S11 (dB)	Δ in Directivity (dB)	Δ in Realized Gain (dB)
1	2.413 (2.398)	-26.546 (-24.702)	0.203	-0.326
2	2.414 (2.4)	-47.189 (-27.091)	0.611	0.133
3	2.415 (2.4)	-30.707 (-27.873)	1.833	1.141

Unlike uni-planar and other EBGs, mushroom-like structures do not have any interconnecting microstrip lines that restrict their placement periodically. Making use of this property, the mushroom-like structures are shifted inwards to the edges of antenna to reduce the overall size of the antenna. Since size is often a limitation in antenna design, the objective was to make it as compact as possible while still offering a favorable performance.

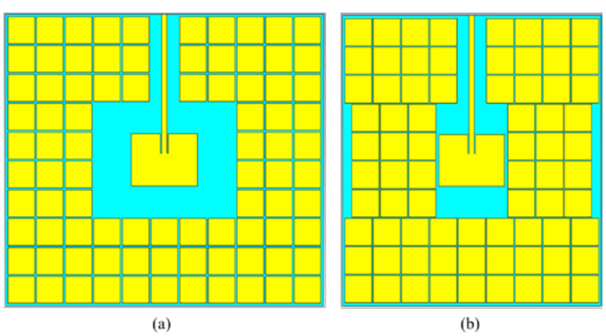

Figure 3. Layout of mushroom-like EBG structures

After variations of the distance between the EBG structure and the edges of the patch antenna, the optimal distance is found. The final design is as shown in Fig. 3(b) with the mushroom-like EBGs shifted inwards a quarter of its period or 4mm. This configuration raised the resonant frequency of the antenna slightly to 2.431 GHz. For a fair comparison on the improved performance, the antenna enhanced by the EBG structures was tuned to resonate at 2.4 GHz and compared with another of the same size but without EBG. The patch width of the mushroom structure was also increased to 15.4 mm to cover the resonant frequency of the tuned antenna. The radiation patterns for the directivity of both antennas are shown in Fig. 4.

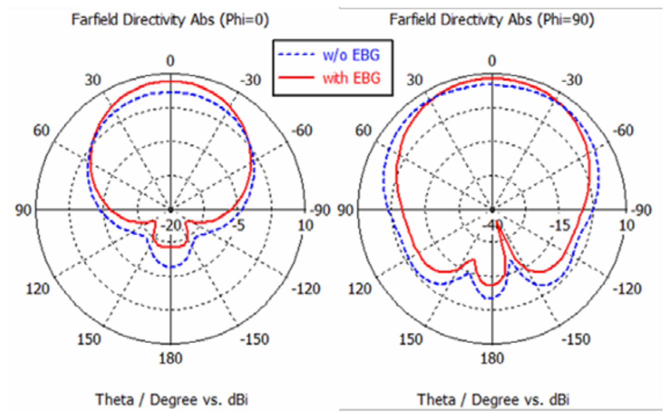

Figure 4. Radiation pattern of mushroom-like EBG structure patch antenna in Fig. 3(b)

From the radiation patterns, it is observed that radiation at the sides and back is reduced and there is a gain in the broadside direction of the antenna. The directivity improved from 6.596 dBi to 8.526 dBi, with the realized gain also showing similar improvements, from 1.462 dB to 3.123 dB.

III. CONCLUSION

A novel application of the mushroom-like EBG has been introduced in this paper. The final design has significant improvements to both its directivity and gain, as compared to the original patch antenna without the use of EBG structures. The flexibility of the placement of the mushroom-like EBG structures is an added advantage in the applications of antenna design. This structure can be applied to any frequency by varying the dimensions of the EBG structure.

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