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# OMNIDIRECTIONAL HORIZONTALLY POLARIZED ANTENNA WITH EBG CAVITY FOR GAIN ENHANCEMENT

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**Abstract**—An omnidirectional horizontally polarized antenna with improved gain is realized by using EBG cavity. The EBG cavity is composed of ring metallic strips etched on thin FR4 substrate and two metallic reflectors installed on up/down sides, which is designed to have a low effective index of refraction ($n < 1$). The metallic strips are arranged in concave shape. Compared with the antenna without EBG cavity, the EBG cavity makes the vertical beam become narrow and effectively improves the omnidirectional antenna gain. An experimental prototype is fabricated to validate the proposed analysis. Measured data show the gain of the antenna with the EBG improved by about 2.72 dBi at 5.7 GHz, and the measured data have a good agreement with numerical results.

## 1. INTRODUCTION

Recently, electromagnetic band-gap (EBG) materials have attracted more attention among researchers due to their interesting characteristics such as negative permittivity, negative permeability, negative permittivity and permeability (DNG), $\varepsilon$-near-zero (ENZ), and positive permittivity less than one [1–3]. EBG materials are usually composed of periodic metallic or dielectric structures, which can inhibit electromagnetic wave propagation in a special frequency range. Periodic metallic cylinder structures possessing low effective permittivities ($\varepsilon < 1$) have been reported in [4–8] to achieve directive radiations. These structures can be analyzed by using plasma theory [9]. Periodic metallic cylinder structures have also been used to realize a directive dual-band antenna [10]. However, most of the previous works are

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about line sources embedded in metallic cylinder EBG materials and the applications for directive radiation. They did not discuss the case that the sources are outside metallic cylinder EBG materials and their application for omni-directional antennas.

In this paper, an EBG material with ring metallic strips etched on thin FR4 substrate is introduced to improve the gain of an omnidirectional horizontally polarized antenna. The EBG material arranged in concave shape is placed around the antenna. The EBG cavity can effectively compress the vertical beam of the antenna. As known to all, it is more difficult to improve the gain of omnidirectional antennas than do that for directive antennas. A dual-frequency omnidirectional antenna [11] has only the gains of 1.7 dBi and 1.2 dBi at 2.45 GHz and 3.9 GHz, respectively. The proposed omnidirectional antenna is designed, fabricated, and measured. Measured data show that the structure can improve the antenna gain by about 2.72 dBi at 5.7 GHz.

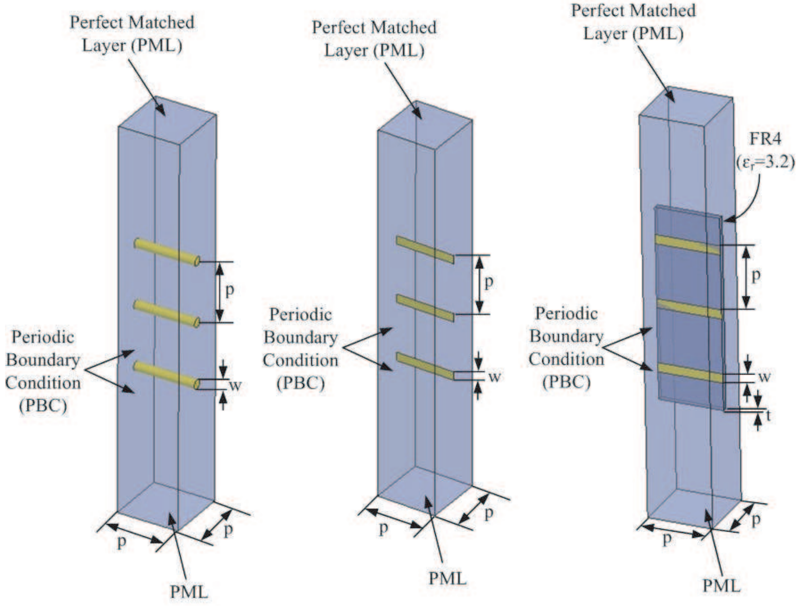
The paper is organized as follows. In Section 2, the effective dielectric permittivity is offered by comparing the simulated $S$-parameters between the proposed EBG material and metallic cylinders EBG material. Snell's law provides theoretical basis for focusing antenna beam and improving gain. Also the configuration of the antenna is exhibited in detail. Simulated and experimental data are described in Section 3. Experimental results verify the theoretical analysis, and the antenna gain is substantially improved. Finally, the results are summarized in Section 4.

## 2. THEORY ANALYSIS AND ANTENNA DESIGN

When a periodic metallic cylinder array has infinite number in periodic expanded direction and infinite length along cylinder direction, the structure will behave as a homogenous material which has an effective dielectric permittivity. The effective dielectric permittivity can be calculated using the following formula [9]:

$$\varepsilon_{\mathit{eff}}(w) = 1 - \frac{w_p^2}{w^2} = 1 - 2\pi c_0^2 / \left[p^2 \ln(p/r) w^2\right] \tag{1}$$

where $c_0$ is the speed of light in the vacuum, and $p$ is the expanded period of the metallic cylinder array. $r$ is the cylinder radius, and $w_p$ is the plasma frequency. In this paper, the metallic strips etched on thin FR4 substrate are used instead of metallic cylinders. Three different EBG materials (metallic cylinders, metallic strips without substrate, and metallic strips etched on thin FR4 substrate) are simulated using Ansoft's High Frequency Structure Simulator (HFSS) v11 [12]. The structures are shown in Fig. 1, and the simulated scattering parameters are shown in Fig. 2. From this figure, the two passband frequencies of type III are lower than those of type I. The EBG material based on the metallic strips etched on thin FR4 substrate is equivalent to the metallic cylinder EBG material which has a larger period $p$. In order to confirm the equivalent $p$ value, the metallic cylinder EBG units with different periods $p$ ($p = 19.5$ mm, 21 mm, 22.5 mm) are simulated, and the simulated scattering parameters are shown in Fig. 3. Comparing Fig. 2 with Fig. 3, we can find that the scattering characteristics of the proposed EBG material are similar to that of the metallic cylinder EBG material having the period $p = 21$ mm. So the proposed EBG material has a similar effective permittivity to the metallic cylinder EBG having the period $p = 21$ mm. There are two passbands for each EBG material in Fig. 2, and the second passband is wider than the first one. In order to make the antenna work better, the second passband is selected for the frequency band of the designed antenna.



(a) (b) (c)

**Figure 1.** Three different EBG units ($p = 19.5$ mm, $w = 1$ mm, $t = 0.8$ mm). (a) Type I: metallic cylinders. (b) Type II: metallic strips without substrate. (c) Type III: metallic strips etched on thin FR4 substrate.

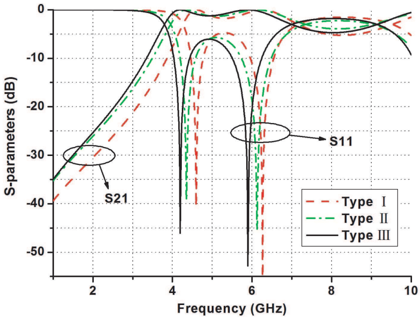


**Figure 2.** Simulated scattering parameters of the three different types of EBG materials.

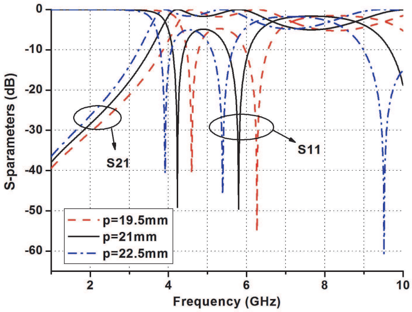


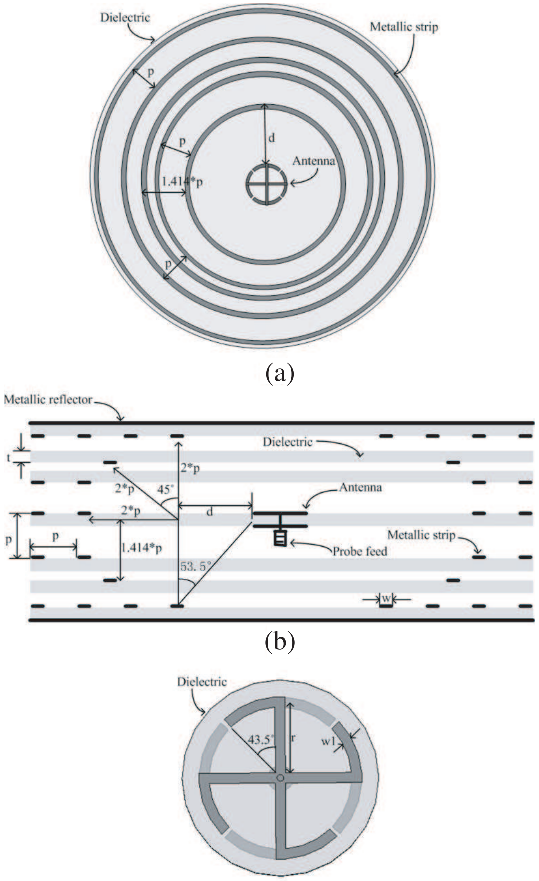
**Figure 3.** Simulated scattering parameters of the cylinder EBG material with different period $p$.

The configuration of the omnidirectional horizontally polarized antenna is shown in Fig. 4. The center Alford structure loop antenna is exhibited in Fig. 4(c), whose dimensions are set as $r = 9.6\,\text{mm}$ and $w1 = 1.2\,\text{mm}$. The antenna is etched on a 0.8 mm thick FR4 substrate with relative permittivity of 3.2 and designed to work at 5.7 GHz. A metallic strip EBG material is added around the antenna, which has a period of $p = 19.5\,\text{mm}$ and is arranged in concave shape. The distance between the antenna and the first row material is $d = 52.75\,\text{mm}$. The width of the metallic strips is $w = 1\,\text{mm}$, and the substrate thickness is $t = 0.8\,\text{mm}$. The radius of curvature of concave shape is 39 mm $(2 * p)$. According to Eq. (1), the effective permittivity of the proposed EBG material is $\varepsilon_{\mathit{eff}} = 0.733$ at 5.7 GHz. The photos of the antennas with and without the proposed EBG cavity are shown in Fig. 5.

When electromagnetic wave propagates from a higher refractive index material to a lower refractive index material via a concave surface and all angles of incidence less than the full reflection angle, the concave surface will achieve convergent function, and the angle of refraction can be calculated according to Snell's law $(n1 * \sin\theta 1 = n2 * \sin\theta 2)$ [13]. The schematic diagram is shown in Fig. 6. The full reflection angle can be modeled as:

$$n1 * \sin i_c = n2 * \sin 90^\circ \tag{2}$$

where $i_c$ is the full reflection angle. When incident material is air, $i_c$ can be denoted as $i_c = \arcsin(n2)$. The proposed EBG material has a full reflection angle of $i_c = \arcsin(\sqrt{\varepsilon_{\mathit{eff}} * \mu_0}) = 58.89^\circ$. The distance $d$ was optimized, and the maximal angle of incidence equals $53.5^\circ$.



(a)

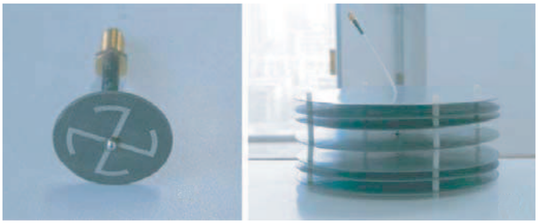
(b)

(c)

**Figure 4.** Proposed omnidirectional antenna. (a) Top view. (b) Cross section view. (c) Center antenna structure.

## 3. SIMULATED AND EXPERIMENTAL RESULTS

All simulations are performed using the full-wave simulator HFSS v11 based on finite element method (FEM). The simulated and measured return losses of the antennas with and without EBG cavity are shown in Fig. 7. As shown in Fig. 7, we can find that the EBG cavity reduces the resonant frequency of the omnidirectional antenna, and there are some difference between the measured $S(1,1)$ and simulated one which may be caused by the stability of the substrate material and the effect of the SMA connectors. Measured 10-dB return losses of the antennas



(a) (b)

**Figure 5.** Fabricated omnidirectional antennas. (a) Without EBG cavity. (b) With EBG cavity.

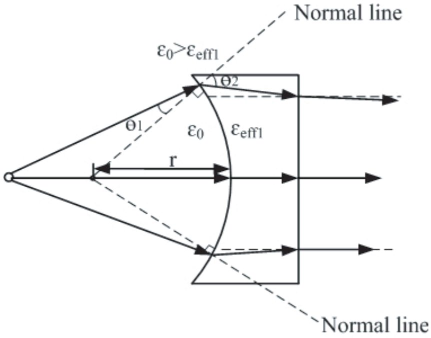
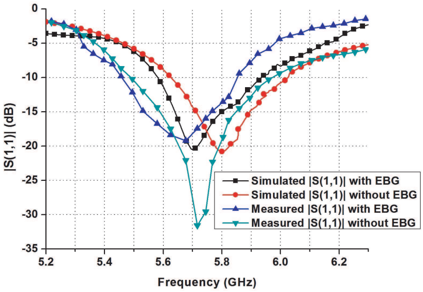


**Figure 6.** Schematic diagram of electromagnetic wave propagating from a higher refractive index material to a lower refractive index material via a concave surface.



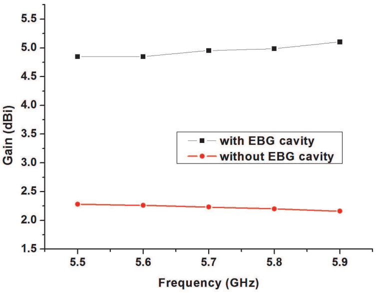
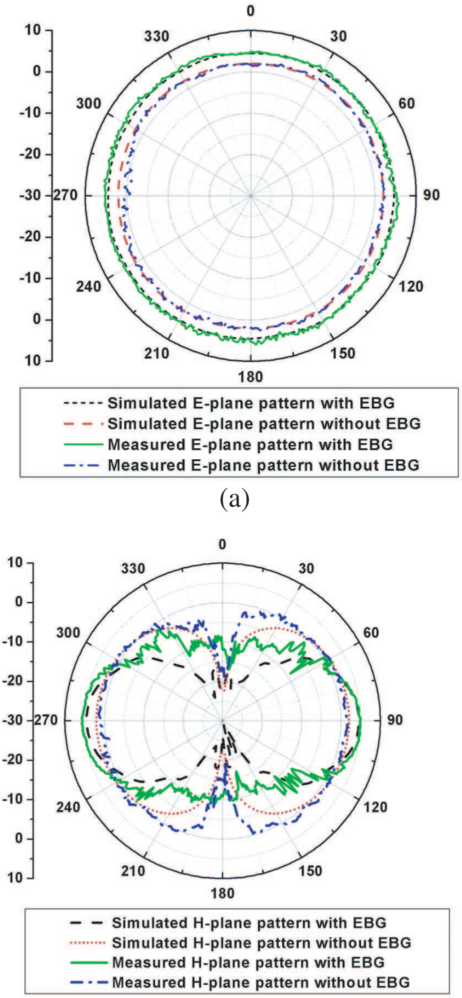


**Figure 7.** Simulated and measured $S(1,1)$ of the antennas with and without EBG cavity.

**Figure 8.** Measured gains of the antennas with and without EBG cavity.



(a)

(b)

**Figure 9.** Simulated and measured radiation patterns of the antennas with and without EBG cavity at 5.7 GHz. (a) *E*-plane pattern, (b) *H*-plane pattern.

with and without EBG cavity are from 5.45 to 5.82 GHz and from 5.49 to 5.95 GHZ, respectively. The measured gains of the antennas with and without EBG cavity are shown in Fig. 8. It is observed from Fig. 8 that the antenna gain can be enhanced by about 2.6 dBi from 5.5 to 5.9 GHz by using EBG cavity. The gains of the antennas with and without EBG cavity are 4.95 dBi and 2.23 dBi at 5.7 GHz, respectively. The simulated and measured radiation patterns of the antennas with and without EBG cavity at 5.7 GHz are shown in Fig. 9. The $E$-plane radiation patterns is omnidirectional, and the $H$-plane beam of the antenna with EBG cavity becomes narrow.

## 4. CONCLUSION

In this paper, metallic strip EBG structures are used instead of metallic cylinder EBG. A concave shaped EBG cavity with ring metallic strips is designed to improve the gain of an omnidirectional horizontally polarized antenna. By adjusting the distance between the source and the peak of the concave surface, the concave shaped interface of the two different materials can effectively compress the vertical beam of the antenna and substantially enhance the antenna gain. Experimental data show that the antenna gain increases by 2.72 dBi at 5.7 GHz.

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