# Influence of EBG Structures on the Far-Field Pattern of Patch Antennas

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**Abstract.** *In this paper, the influence of the EBG structures on the far-field pattern of patch antennas is investigated. As a reference model, a conventional rectangular patch antenna on a high-permittivity substrate is used. The reference model is consequently equipped by an EBG substrate (instead of the conventional one), and by an EBG cover (so called EBG superstrate). The changes in the far-field radiation patterns are discussed.*

*In the second part of the paper, the substrate is perturbed by two different EBG structures designed for the coverage of two operation bands.*

## Keywords

Patch antenna, EBG substrate, far-field radiation pattern, double-band antenna, superstrate.

## 1. Introduction

In recent years, different types of antennas have been used in wireless services. Very popular planar antennas (e.g. patch ones) excel in a low cost, a low profile and a simple mass production. On the other hand, patch antennas exhibit a narrow bandwidth and low gain. Moreover, surface waves can be excited in the substrate, which decreases the antenna efficiency [1].

Propagation of the surface waves can be suppressed by using periodic structures called Electromagnetic Band Gap (EBG) ones. EBG structures can be implemented as metallic-dielectric ones (elements of the periodic layout are etched to the electroplated substrate) and purely dielectric ones (typically, holes are drilled into the dielectric medium).

Exploitation of both the types of periodic structures was described in several papers. The metallic-dielectric structures were applied to single-band patch antennas and double-band ones positively influencing their radiation patterns and gain [2] – [5]. The purely dielectric EBG structures were applied both in the substrate [6], [7] and in the superstrate of the patch antenna focusing the main beam and increased gain [8]. Nevertheless, all the published papers presented purely dielectric EBG structures for the single-band exploitation only; or for the operation in two closely neighboring bands.

In the open literature, we have not found any paper describing a fully-dielectric EBG structure designed for the coverage of two distant operation bands. The double-band EBG structure proposed in this submission is therefore considered to be the original contribution of the paper.

## 2. Design of the EBG Structures

In the paper, a purely dielectric EBG structure is used to suppress surface waves. The EBG structure is formed by holes drilled into the dielectric material Arlon AR1000 with the dielectric constant 9.8, dissipation factor 0.003, and thickness 3.125 mm. Arlon AR1000 is chosen due to the higher excitation of surface waves.

The dimensions of the EBG structure are obtained from an atlas of gap maps [9] through the approximate values of ratios $r/a$, and $f\,a/c$. Here, $r$ is the radius of holes, $a$ is the lattice constant, $f$ denotes frequency and $c$ is the velocity of light. The dimensions $r$ and $a$ are designed so that the band gap for covering the operation band of the antenna can appear between the higher excited modes in the substrate. The investigations are focused on the band gaps between transversally magnetic modes (TM) only since the central frequency of the higher operation band (7.0 GHz) is lower than the cut off frequency of the $TE_1$ mode (8.0 GHz).

The cut off frequency can be calculated using [10]:

$$f_c = \frac{n}{4h\sqrt{\varepsilon_0\mu_0}\sqrt{\varepsilon_r\mu_r - 1}} \, , \qquad (1)$$

where $h$ is the thickness of the substrate, $\varepsilon_0$ and $\mu_0$ are permitivity and permeability of the vacuum, $\varepsilon_r$ and $\mu_r$ are relative permitivity and permeability of the dielectric material, $n$ = 0, 2, 4, … for TM modes and $n$ = 1, 3, 5, … for TE modes.

The main parameters of the EBG structure can be accurately computed by the program MIT Photonic Band Package [11]. We obtained $a$ = 42.1 mm and $r$ = 20.95 mm for the lower operation band with the central frequency 5.175 GHz (the bandwidth is 1.1%), and $a$ = 31.2 mm and

$r$ = 15.5 mm for the higher operation band with the central frequency 7.000 GHz (the bandwidth is again 1.1%).

# 3. Design and Simulations of Patch Antennas

## 3.1 Antenna on Conventional Substrate

First, a simple patch antenna on a conventional substrate is modeled and simulated to obtain far-field patterns. The rectangular patch is designed to operate at the frequency 7.000 GHz. The dimensions of the antenna are depicted in Fig. 1. The antenna is fed by a coaxial probe situated in the distance 1.55 mm from the center of the patch. The total size of the antenna is set with regard to the computed parameters of the EBG structure.

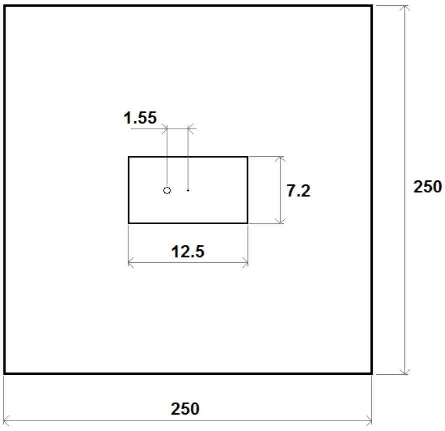


**Fig. 1.** Dimensions of the antenna in millimeters.

The antenna was modeled and simulated in CST Microwave Studio (MWS). The computed impedance matching and directivity patterns of the antenna for frequency 7.000 GHz are depicted in Fig. 2 and Fig. 3. Obviously, the patch antenna is matched well at the desired frequency, and does not radiate perpendicularly to the plane of the substrate. In order to verify obtained results, the antenna was computed in Ansoft HFSS also (frequency domain finite elements versus time domain finite differences).

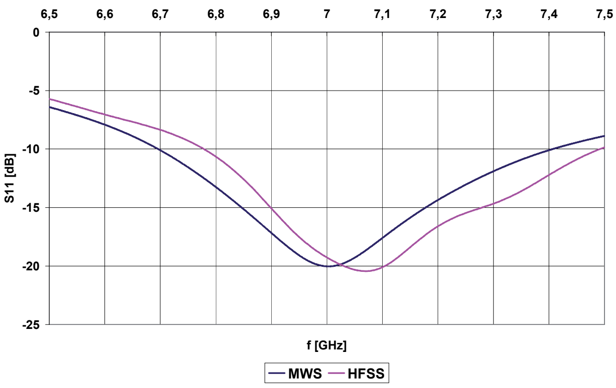


**Fig. 2.** Frequency response of the reflection coefficient of the patch antenna on the conventional substrate.

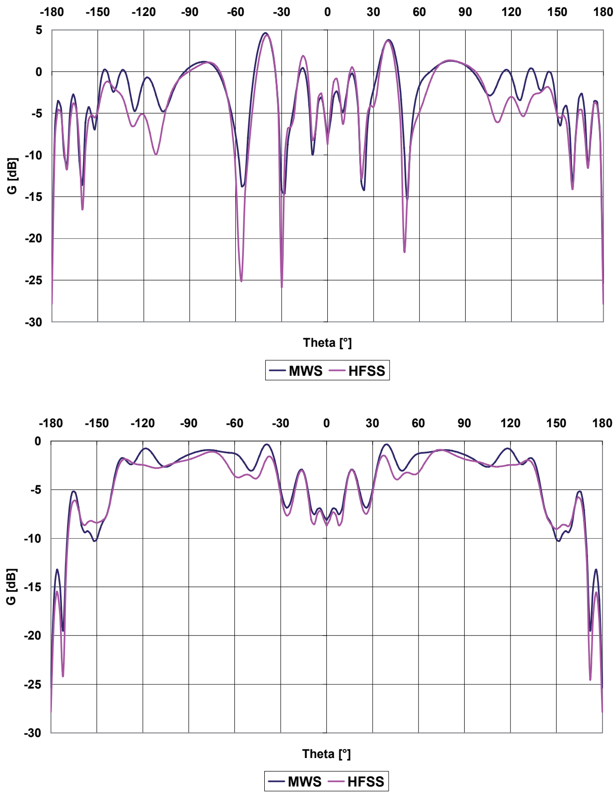


**Fig. 3.** Directivity patterns of the patch antenna on the conventional substrate in E plane (top) and H plane (bottom). The angle Theta = 0 is perpendicular to the plane of the antenna.

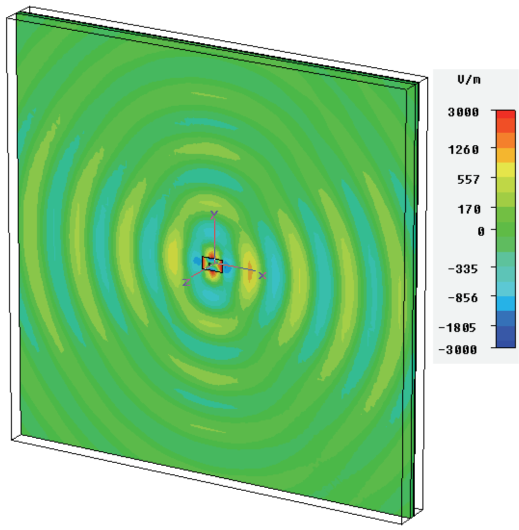


**Fig. 4.** Distribution of the *Ez* component (perpendicular) of the antenna on the conventional substrate.

## 3.2 Antenna on EBG Substrate

In order to enhance the antenna radiation in the perpendicular direction, the EBG structure replaces the conventional substrate (three rows of holes are drilled around the patch). The length of the patch is changed to 12.6 mm. Fig. 5 and Fig. 6 show that the antenna is well matched again but the radiation pattern does not change significantly. Only some side lobes are unified and the gain is increased slightly in the main lobe direction.

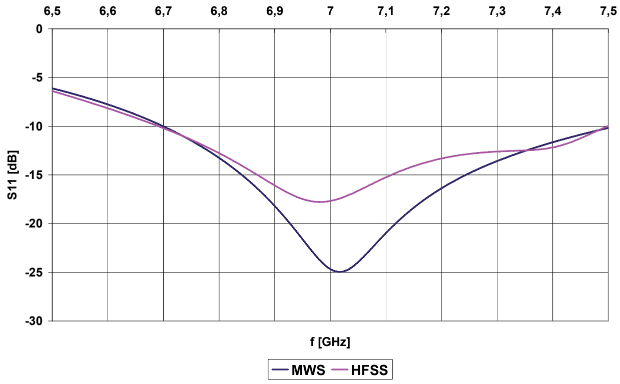


**Fig. 5.** Frequency response of the reflection coefficient of the patch antenna on the EBG substrate.

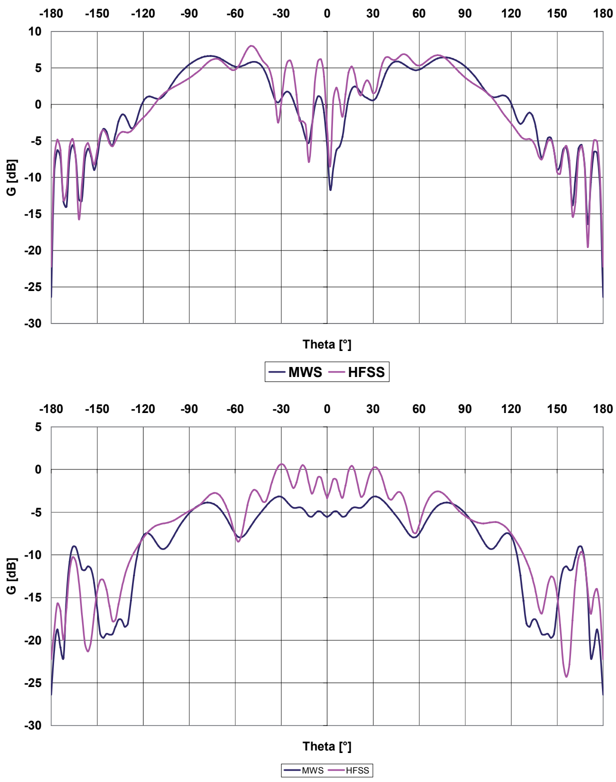


**Fig. 6.** Directivity patterns of the patch antenna on the EBG substrate in E plane (top) and H plane (bottom). The angle Theta = 0 is perpendicular to the plane of the antenna.

The EBG substrate did not significantly influence the directivity pattern since the main direction of the patch radiation was not directly oriented to the plane of the substrate but was deflected by 10° over the plane of the substrate approximately.

### 3.3 Antenna on EBG Substrate Covered by EBG Superstrate

In order to improve the perpendicular radiation, an EBG *superstrate* of the same parameters like the substrate is added to the antenna with zero distance from the top of the substrate. Hence, the patch is *drowned* now in the dielectric material of total thickness 6.25 mm.

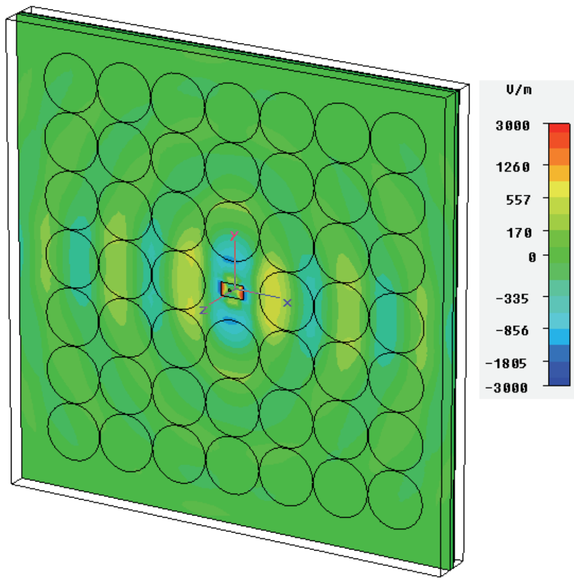


**Fig. 7.** Distribution of the *Ez* component (perpendicular) of the antenna on the EBG substrate.

In order to keep the antenna well matched, the length and the width of the patch are changed to 13.32 mm and 8.00 mm. The coaxial excitation is moved to 2.00 mm.

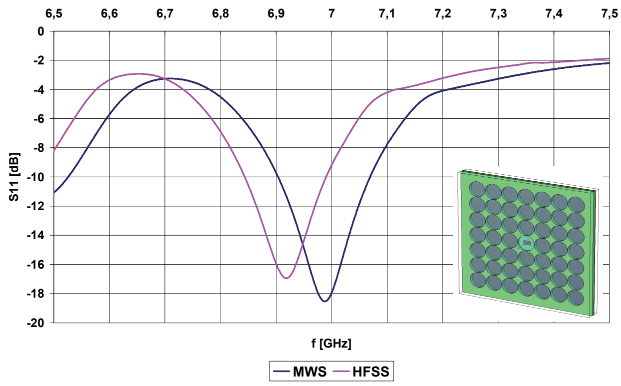


**Fig. 8.** Frequency response of the reflection coefficient of the patch antenna on EBG substrate with EBG superstrate. The model of the antenna on the EBG substrate is depicted in the corner.

Obviously, the nearly perpendicular radiation is achieved (Fig. 9), and the gain is increased by 4 dB approximately.

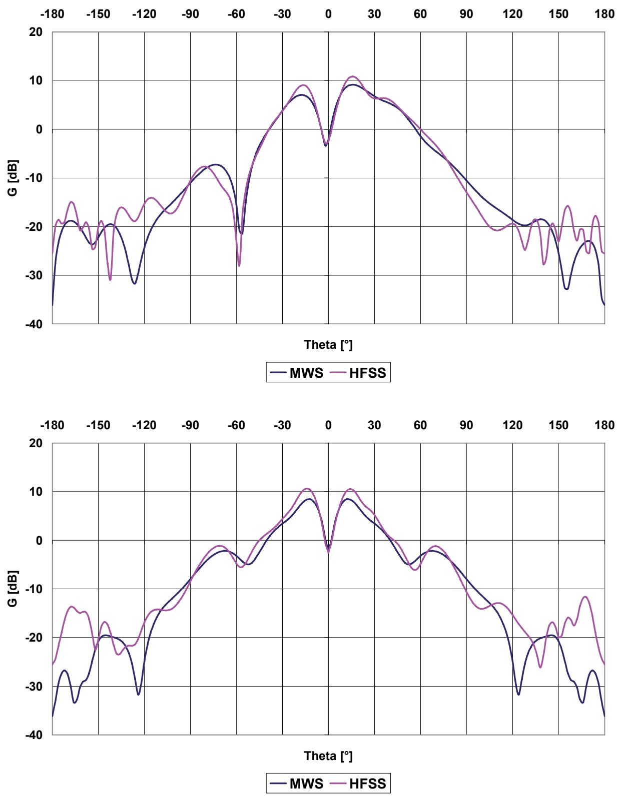


**Fig. 9.** Directivity patterns of the patch antenna on the EBG substrate with EBG superstrate in E plane (top) and H plane (bottom). The angle Theta = 0 is perpendicular to the plane of the antenna.

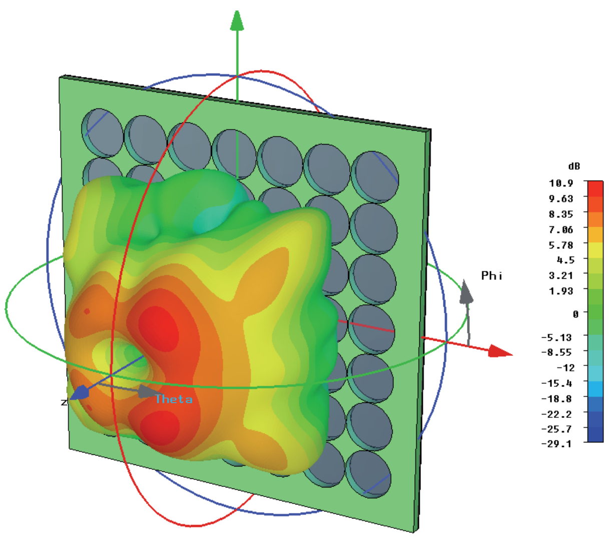


**Fig. 10.** Three-dimensional directivity pattern of the patch antenna on the EBG substrate with the EBG superstrate.

Fig. 10 shows that most energy is radiated in the nearly perpendicular direction.

### 3.4 Antenna for Lower Band

In final, two different EBG structures for two different frequency bands are placed around the patch to suppress surface waves in two operation bands: the 7.000 GHz one and the 5.175 GHz one.

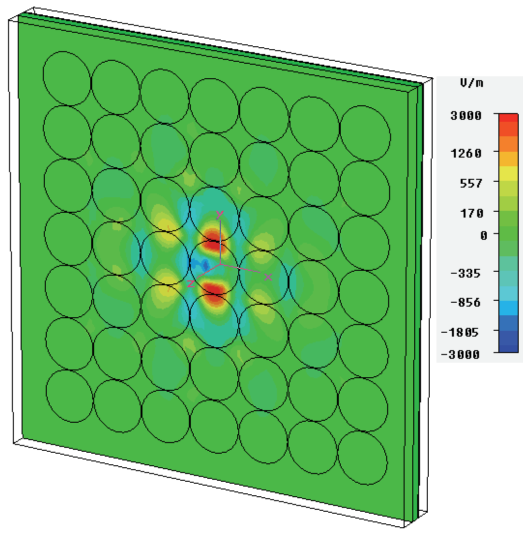


**Fig. 11.** Distribution of the $E_z$ component (perpendicular) of the antenna on the EBG substrate with the EBG superstrate.

The influence of the lower-band EBG structure to the wave propagation in the lower frequency band is tested by a simple patch. For the conventional substrate, the patch is of the length 16.46 mm, of the width 9.3 mm, and the coaxial feeding is in the distance 3.9 mm from the patch center. For the EBG substrate, patch dimensions are changed to the length 16.55 mm, to the width 9.4 mm, and the feeding point is moved to the distance 3.75 mm from the patch center. Frequency responses of the reflection coefficients for both the structures are depicted in Fig. 12.

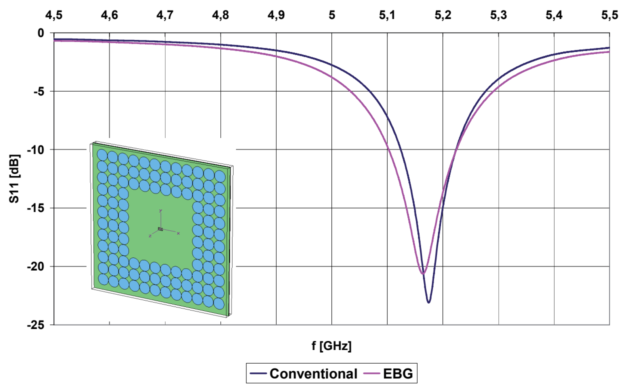


**Fig. 12.** Comparison of the frequency response of the reflection coefficient of the patch antenna on the conventional substrate and on the EBG substrate in lower frequency band. The model of the antenna on the EBG substrate is depicted in the corner.

Fig. 13 and Fig. 14 show the directivity patterns of the patch on the conventional substrate and the EBG one. Evidently, the patterns of low-frequency waves are affected by the EBG structure slightly.

Finally, the antenna structure (the patch and the high-frequency EBG substrate) is complemented by the EBG structure for the low-frequency band (holes of a larger radius around the high-frequency EBG). Moreover, the antenna is covered by the EBG superstrate, which is identical with the substrate. The thickness of the final structure is 6.25 mm. The size of the whole antenna is 540 mm × 540 mm. The final model of the antenna is depicted in Fig. 15.

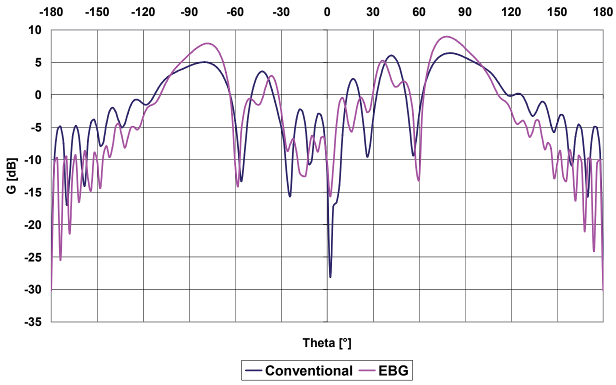


**Fig. 13.** Comparison of the directivity patterns of the patch antenna on the conventional substrate and on the EBG substrate in lower frequency band for E plane.

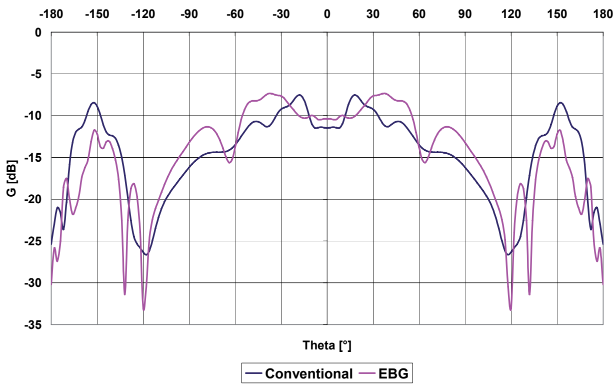


**Fig. 14.** Comparison of the directivity patterns of the patch antenna on the conventional substrate and on the EBG substrate in lower frequency band for H plane.

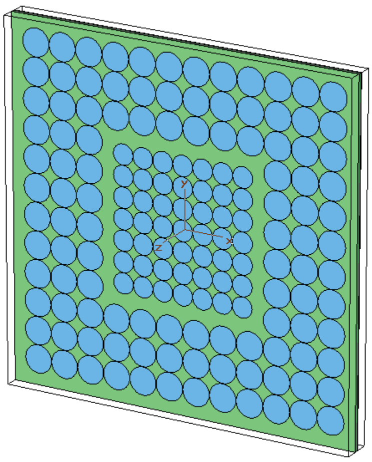

**Fig. 15.** Top view on the model of the antenna with the dual-band EBG superstrate and the identical EBG substrate.

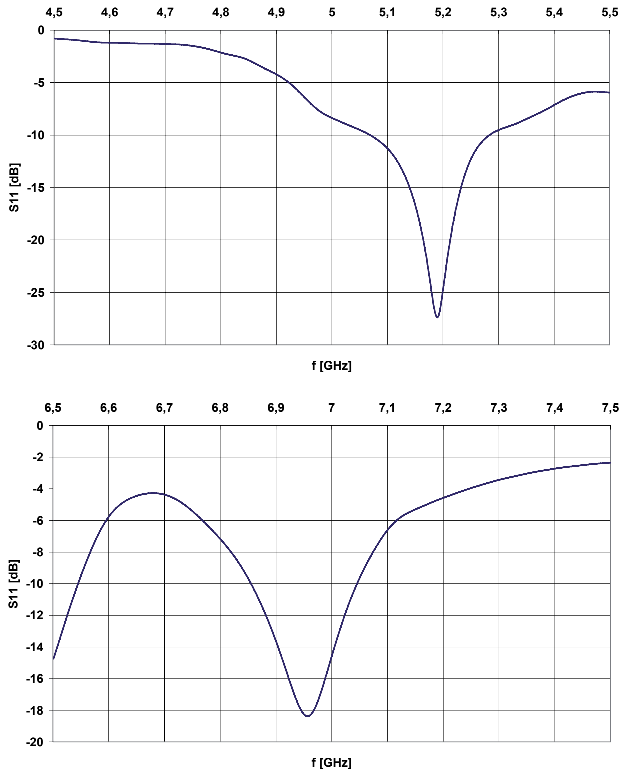


**Fig. 16.** Frequency response of the reflection coefficient of the patch antenna on the dual-band EBG substrate completed by the dual-band EBG superstrate in the lower frequency band (top) and the higher frequency band (bottom).

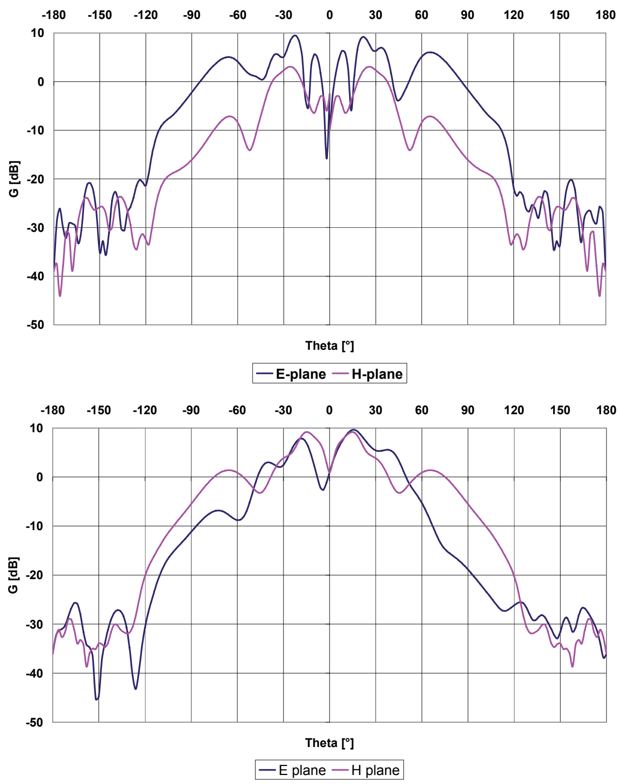


**Fig. 17.** Directivity patterns of the patch antenna on the dual-band EBG substrate completed by the dual-band EBG superstrate in the lower frequency band (top) and the higher frequency band (bottom).

Numerical simulations of the patch antennas on the dual-band EBG substrate completed by the dual-band superstrate show a good impedance matching at the operation frequencies (Fig. 16): $s_{11} < -25$ dB at the lower frequency, and $s_{11} < -18$ dB at the higher one.

Directivity patterns of the antennas in both the frequency bands are depicted in Fig. 17: the influence of the high-frequency EBG structure to the low-frequency radiation is weak, and vice versa.

Three-dimensional radiation patterns of the EBG antennas for both the frequency bands are depicted in Fig. 18, and the distribution of the perpendicular $E_z$ component is given in Fig. 19.

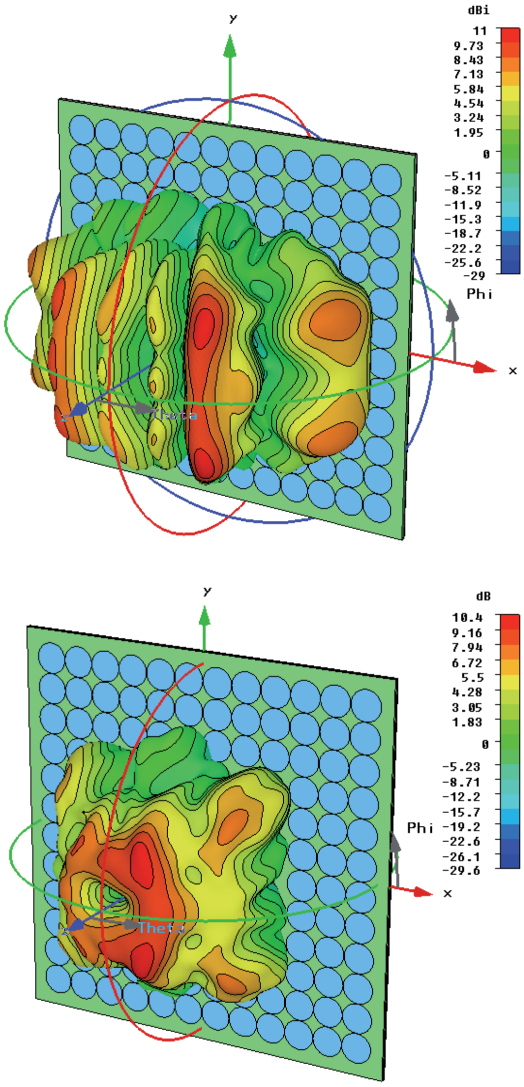


**Fig. 18.** The three-dimensional directivity pattern of the patch antenna on the dual-band EBG substrate completed by the dual-band EBG superstrate in the lower frequency band (top) and the higher frequency band (bottom).

Both Fig. 18 and Fig. 19 show that the antenna radiation in the lower frequency band is not influenced by the high-frequency EBG structure, and vice versa.

## 4. Conclusion

In the paper, the EBG concept was applied to the design of two simple patch antennas with different frequency bands in order to suppress the surface wave propagation in the dielectric substrate (an EBG substrate) and improve the radiation in the perpendicular direction (an EBG superstrate). Both the substrate and the superstrate were of the same geometry.

The EBG structures were conceived as an inner EBG region and an outer one. The inner EBG region suppressed the propagation of high-frequency waves, and did not influenced low-frequency waves. The outer EBG region suppressed the low-frequency waves, which passed through the inner EBG region.

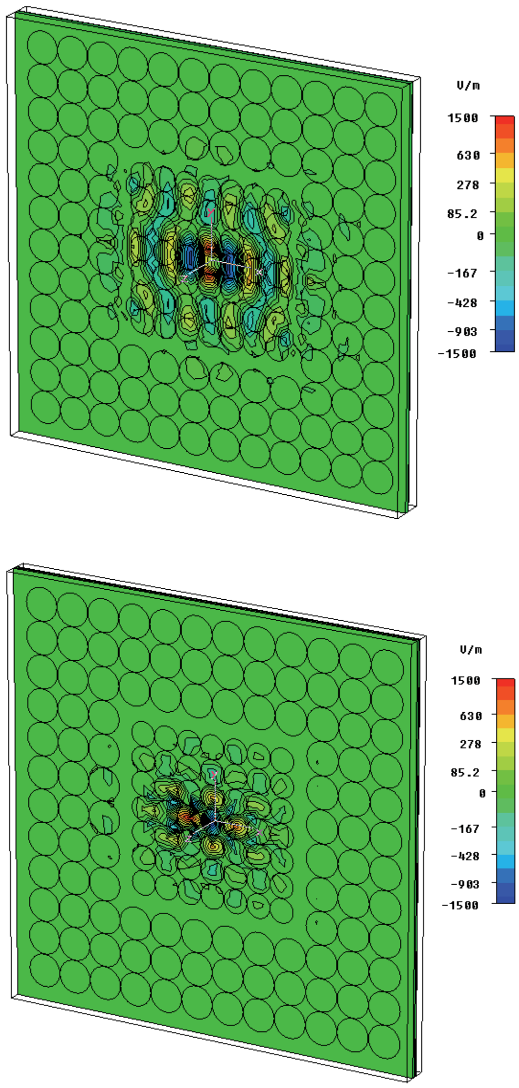


**Fig. 19.** Distribution of the $E_z$ component (perpendicular) of the patch antenna on the dual-band EBG substrate completed by the dual-band EBG superstrate in the lower frequency band (top) and the higher frequency band (bottom).

Properties of the dual-band EBG structure were tested by computer simulations in CST Microwave Studio and Ansoft HFSS. Both the programs provided comparable results proving a good impedance matching, satisfactory surface wave suppression, and an improved radiation in both the investigated frequency bands.

Properties of the designed antenna are going to be verified by an experiment in a near future.

## Acknowledgements

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