ISSN 0005–1144
ATKAAF 49(3–4), 143–150 (2008)

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Metallic EBG Sectoral Antennas with different Polarizations

UDK 621.396.677
IFAC 5.8.1

Original scientific paper

This work aims to study and design antennas for base stations with metallic electromagnetic band gap (EBG) materials. The objective was to make and study new concepts of EBG metallic antennas able to work according to a wide (or broad) radiation pattern form, i.e. presenting at least 60° angular beamwidth. The use of metallic structures offers a new approach to industrial partners in order to reduce costs and to facilitate design techniques. The high impedance presented by the metallic structure allows us to use only one layer of rods and to make the antenna more compact than the one with a dielectric structure.

Key words: metallic Electromagnetic Band Gap (EBG) antenna, sectoral pattern, printed antenna, vertical polarization, horizontal polarization, dual polarization

1 INTRODUCTION

The electromagnetic band gap EBG materials are periodic structures which the wave propagation for certain frequency bands and certain incidence angles is prohibited [1]. The insertion of a defect within the crystal EBG periodicity can create a transmission peak inside the forbidden band. It was proven that by exciting the defect structure at the transmission peak frequency, it is possible to design antennas with interesting performances. The one-dimensional radiation is ensured by the insertion of a ground plane in the middle of the defect [2]. The analyses show that the EBG antenna is a resonator cavity, it thus define a radiation aperture antenna whose gain is directly related to the size of the equivalent radiant surface which is fixed by the material electromagnetic properties, therefore it is obvious that the radiation patterns shape depends directly on the cavity modes excited in the defect.

To have a good radiation with a relatively significant gain, the radiant spots must be well interlaced and equiphase on the structure upper surface. In fact, the field distribution in a transverse section in the cavity presents a maximum in the middle and then decreases gradually towards the antenna edges. However, it is the case of a radiation in evanescent cavity mode. The cavity height must be selected so that its cut-off frequency is slightly higher than the upper bound of the antenna band operation (Δf_0) (Fig. 1). In addition, the antenna will function right before the propagating cavity mode, i.e. at its evanescent mode; in this case the radiation surface is large with few field variations related to a good spots interlacing.

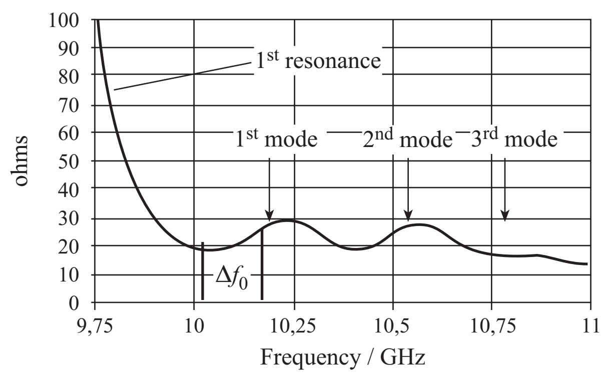

Fig. 1 Real part of the impedance entry

The realized EBG antennas present an omnidirectional [3] or directive radiation [2]. Our objective was to obtain a metallic EBG antenna [4] able to radiate according to a sectoral form pattern presenting a half power beamwidth of at least 60° in one of the planes [5]. There are many types of antennas presenting such a pattern, as the butler matrices or the antennas arrays, but they require complicated feeding mechanisms.

2 PRINCIPLE OF A SECTORAL METALLIC EBG ANTENNA

In case of a square antenna, the radiant aperture has a ring form, as shown in Fig. 2. Therefore, the radiation pattern presents the same aperture in both vertical and horizontal plane [2].

To get a sectoral antenna, it is necessary to change from a circular to an elliptic spot (Fig. 3).

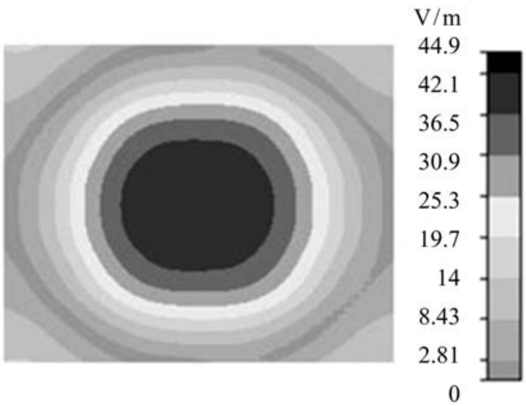

Fig. 2 Circular aperture

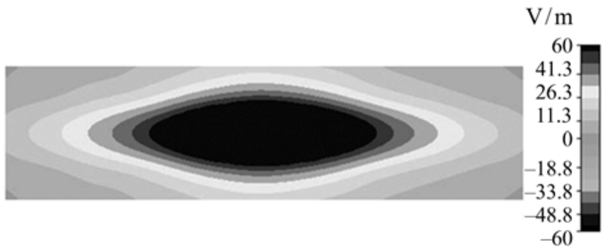

Fig. 3 Elliptical aperture

The simplest solution to obtain an elliptic radiant aperture is to give the EBG structure a rectangular form [5], by introducing vertical »walls« into the cavity (Fig. 4).

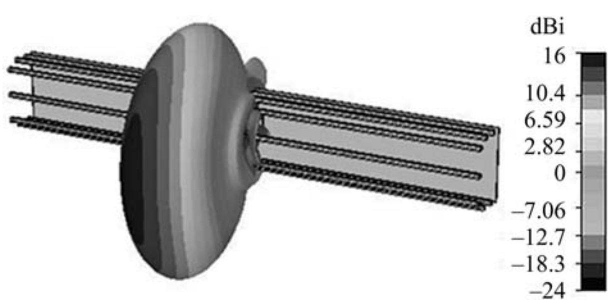

Fig. 4 3D radiation pattern of the sectoral antenna

To explain this method we will consider the EBG structure antenna as a evanescent cavity excited by a wave guide and limited by a short-circuit (SC) like a metal plate placed perpendicularly to the guide axis (Fig. 5).

In fact, the field distribution in a transverse section in the evanescent cavity must present a maximum and then decrease gradually towards the metal plate edges without phase variation. The short-circuit annuls the tangential field *Ey* on the

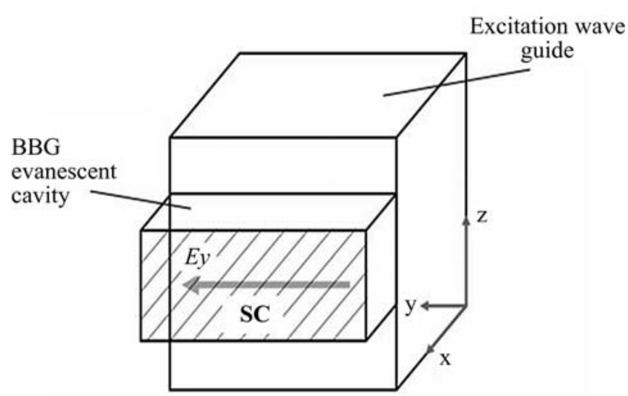

Fig. 5 EBG evanescent cavity

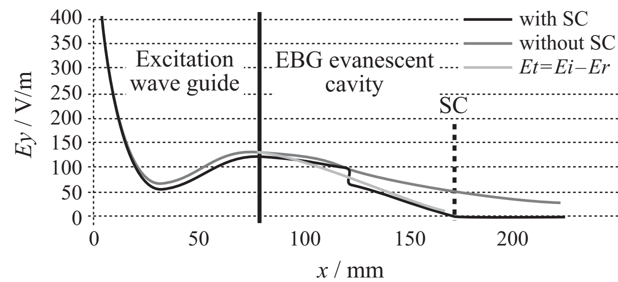

Fig. 6 The electric field vs. the cavity width (x)

metallic wall. The wave injected into the evanescent cavity decreases exponentially and is reflected on the SC wall by generating a wave in phase-opposition which is subtracted from the incidental wave. The total wave also created has a very fast decrease and is annulled at the structure edge. Whereas without the SC, the wave would have a side decrease slower and would flee out of the structure (Fig. 6). In addition, it is very important to note that the phase remains constant along the evanescent cavity (Fig.7).

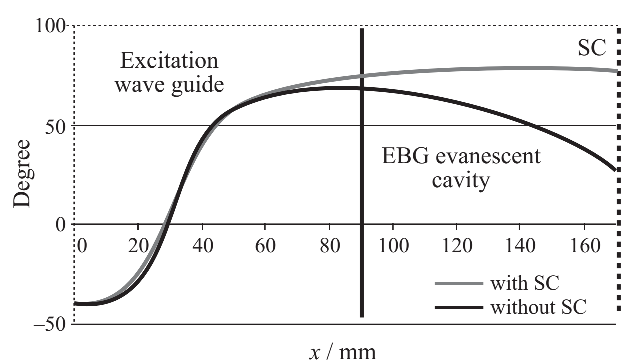

Fig. 7 The electric field phase vs. the cavity width (x)

The wall confines the field and maintains it inside the cavity by limiting its spreading out in the horizontal plane. Consequently, the radiant spot is extended and takes an elliptic form. The reflection entrains a reduction in the maximum gain but also reduces the losses of the field and thus decreases the side lobe levels.

3 MODELING OF THREE EBG ANTENNAS WITH DIFFERENT POLARIZATIONS

3.1 Sectoral antenna for a UMTS base station in vertical polarization

3.1.1 Presentation and Description

The objective is to design a new type of antenna matched always for wireless telecommunication networks base stations: our sectoral metallic EBG monobande antenna satisfies the uplink UMTS schedule specification (1.92–1.98 GHz) [6] with 18 dB gain and a radiation beam-width of 60° in the horizontal plane. This antenna uses only unidimensionnal structures in TM polarization (the rods are parallel to the *E* field); feed ports and metallic rods must be in a vertical distribution.

The EBG metallic antenna is composed of three principal parts (Fig. 8):

1. The ground plane where the system feeding rests.
2. A cavity located between the ground plane and the metallic rods.
3. The EBG structure made by periodic metallic elements.

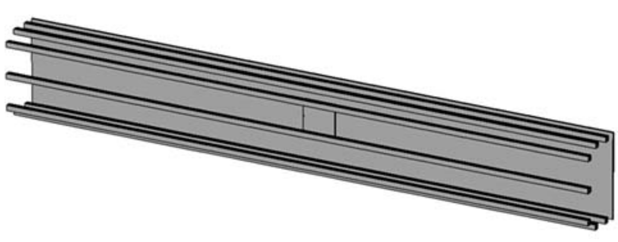

Fig. 8 Geometry of the sectoral monosource antenna

The fundamental element of this EBG metallic antenna is the resonant cavity where energy is stored. This cavity should not be electromagnetically disturbed by its internal feeding system. To obtain a good result, this system must have small overall occupancy in the volume defined by the cavity.

Several sources can suitably feed this resonant EBG antenna such as horn antennas, dipoles in ground plane, but the antenna which seems most adequate is the printed one [7]. Indeed, they are well controlled, light, not very bulky and not very expensive.

The metallic EBG structure in TM polarization is designed with 3 rods of 10 mm width in order to regulate the forbidden band around 2 GHz. Rods period is 60.5 mm and their thickness is 10 mm.

We choose a rectangular section for our rods in order to have a simpler structure to define and to realize.

The simulated ground plane has the same size as the structure i.e. 900×164 mm^2. The patch dimensions fix its resonance at 1.85 GHz in order to suitably feed the cavity created between the metallic EBG structure and the ground plane.

The antenna cavity height will be determined by the following relation (1), where the phases $\angle_{\mathrm{EBG}}$ and $\angle_{\mathrm{Walls}}$ correspond to the reflection coefficient of EBG structure and walls defining the cavity respectively and l is the width of the antenna:

$$h = \frac{1}{2} \frac{c\left(\frac{1}{2} + \frac{\angle_{EBG}}{360}\right)}{\sqrt{f^2 - \frac{c^2}{4\,l^2}\left(\frac{\angle_{Walls}}{180}\right)^2}} \qquad (1)$$

The EBG structure is thus situated at 80 mm over the ground plane, which is about $\lambda_0/2$. Its operating frequency is around 1,95 GHz.

The metallic rods disposed on vertically antenna sides have dimensions of 10×10 mm^2.

At the beginning, the antenna gain with only one feeding source (Fig. 8) was about 16 dBi with a narrow operating band-width.

3.1.2 Input Impedance

The resonant frequency of the antenna varies according to the cavity height thus the frequency of the exciting antenna is slightly shifted by EBG structure. Figure 9 represents an example of input impedance which reveals several peaks of resonance.

The stronger amplitude observed in the first peak (1.85 GHz) corresponds to the first resonance related to the patch antenna in the presence of EBG structure. The first mode in the cavity is at 2 GHz. There are several parameters which influence the antenna performances. The filling ratio is one of the most important parameters.

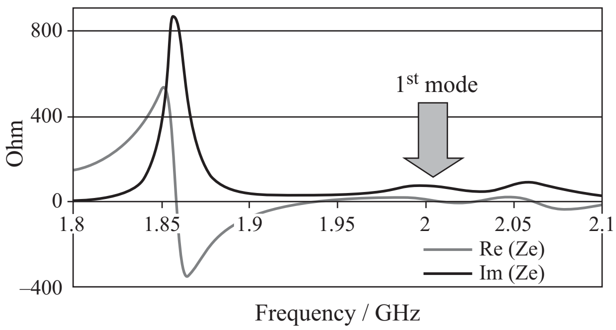

Fig. 9 Real and Imaginary parts of the input impedance

3.1.3 Filling ratio

The EBG structure formed by metallic rods can be dimensioned by considering certain parameters like rods section (w), rods period (p), in other terms by defining the filling ratio (τ). The filling ratio has a big influence on the antenna performances (Directivity and Band-width). W and p values are fixed according to the value of the filling ratio. The filling ratio is defined by (2):

$$\tau = \frac{w}{p} \tag{2}$$

The studied antenna is made of 3 metallic rods. Several values of τ are considered by modifying w and p values. The following table (Table 1) shows the w and p variation related to τ (Fig. 10).

Table 1 **Different values of *W* and *p***

	W (mm)	p (mm)
$\tau = 0.082$	5	60.5
$\tau = 0.165$	10	60.5
$\tau = 0.247$	5	60.5

Figure 11 shows relative curves of the directivity according to the frequency.

The curves (1), (2) and (3) show that by increasing the filling ratio, the directivity increases and

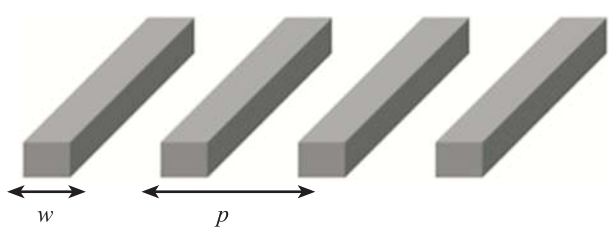

Fig. 10 w and p values following π

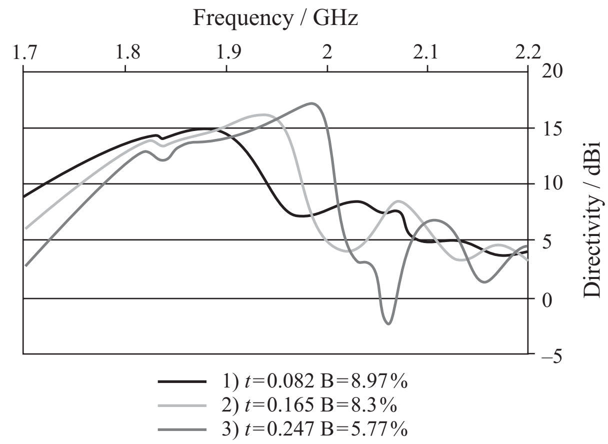

Fig. 11 Directivity evolution for the three cases

the band-width B decreases. Then, if an important band-width is needed, the solution is to decrease the filling ratio.

3.1.4 Performances enhancement

The objective of this paragraph is to propose solutions in order to improve the antenna performances in term of Directivity and band-width.

The antenna fed by multiple sources will enhance its performances.

a) Principle of multisource technique

The metallic 1D EBG antenna behaves like a radiation aperture with a relatively homogeneous field's distribution on the working fundamental mode.

The principle of the multiple sources feeding is based on the arrays theory, which allows increasing directivity by the summation of various elements contributions [8].

Thus, by exciting the resonant cavity with multiple sources, we realize an interlaced radiation apertures network which makes it possible to obtain a more important directivity by summation of the apertures contribution.

Then the use of multisource technique enable us to increase the directivity and the band-width with an aim of reaching the 18 dB desired gain. The following part will explain the principle in more detail.

b) Set-up of the sources and radiation aperture

The feeding system of the structure will be provided by patch. We chose this element for its compactness, and its rather easy setting in array antenna by the printed elements technology.

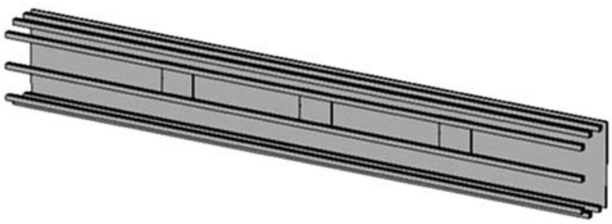

Fig. 12 Geometry of the sectoral multisource antenna

The patch antenna are regularly laid out on a ground plane (Fig. 12) in order to constitute an array, the necessary sources number and the distance between sources were thus selected in order to obtain the best improvement in terms of directivity.

To observe the phenomenon, we will study the electric field distribution in the antenna. The dimension of the multisource antenna will be extended to contain the radiation spot (1200×164 mm^2).

For each case, the electric field distribution in a horizontal plane of the resonant cavity for the working central frequency (1.95 GHz) is given.

c) Monosource Case

The simplest case consists of only one source centered in the ground-plane.

Let us observe for this antenna the tangential electric field distribution in the middle of the resonant cavity (Fig. 13). The spot dimensions indicate the potential directivity of the antenna. Now let us study the multisource technique in the resonant cavity.

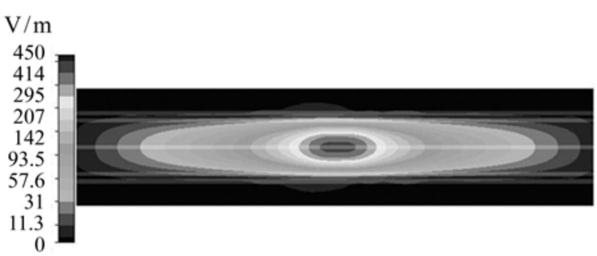

Fig. 13 Distribution of the tangential electric field module |Ex|

d) Multisource Case

The multisource structure presents three sources spaced by 1.5 λ_0 in order to obtain a good apertures interlacement. Moreover, lateral dimensions of the antenna are extended in order to maintain all energy in the cavity.

The sources are fed with the same current in amplitude and phase.

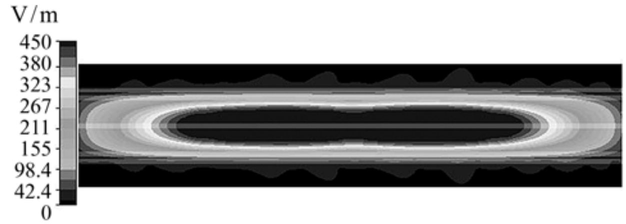

Fig. 14 Distribution in the multisource case

In this case (Fig. 14) the radiant surface is large with few variations of the field due to a good spots interlacing.

It is thus possible due to EBG metallic material and several feeding sources to realize a large radiant surface by controlling the field distribution on this aperture relatively to the sources position in the ground-plane.

Let us pass now to the frequency directivity of these structures.

3.1.5 Directivity

Simulation results of metallic EBG antenna directivity are shown in Figure 15, for each case according to the frequency.

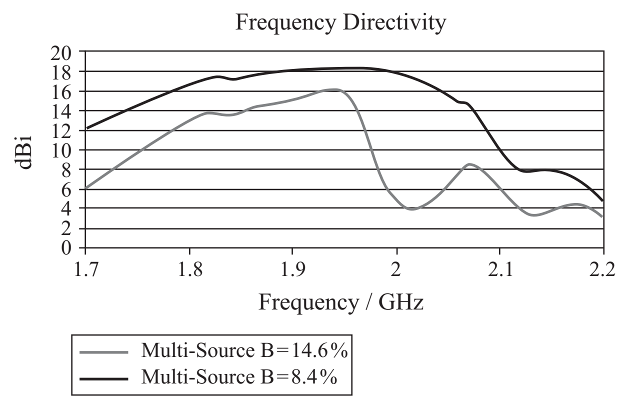

Fig. 15 Directivity evolution for the two cases

The use of the multi-source technique enabled us to increase at the same time the gain and the band-width B. It is thus noted that this technique can give very interesting results: between the two extreme cases, the directivity is increased by 2.2 dBi (from 16 to 18.2 dBi) and the band-width passes from 8.4% to 14.6%.

3.1.6 Simulated results of the final structure

Figure 16 represents the radiation pattern in vertical (E) and horizontal (H) planes of the antenna.

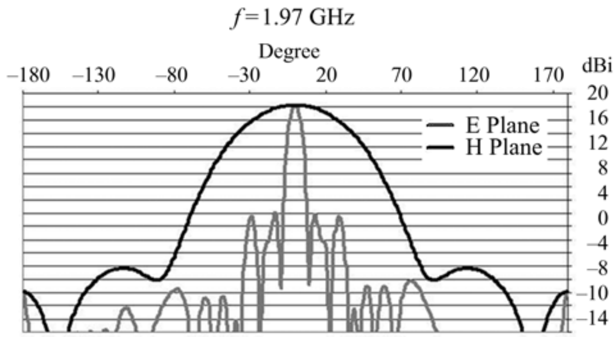

Fig. 16 Radiation patterns at 1.97 GHz

The antenna is directive in E-plane and sectoral in H-plane (65°). The maximum directivity reaches 18.3 dBi.

The patterns have low side lobes, so we can estimate that the structure is well dimensioned.

The return loss shown on Figure 17 is satisfying, since reaching the −10 dB on all frequency bands.

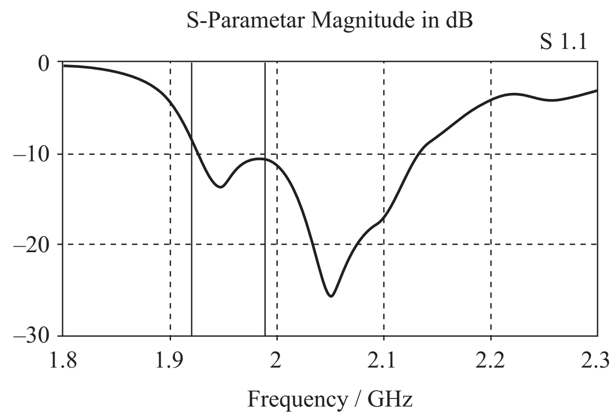

Fig. 17 Return loss

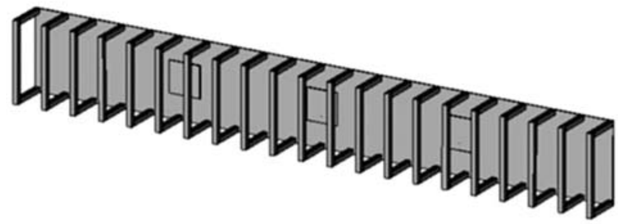

Fig. 18 Geometry of the sectoral multi-source antenna

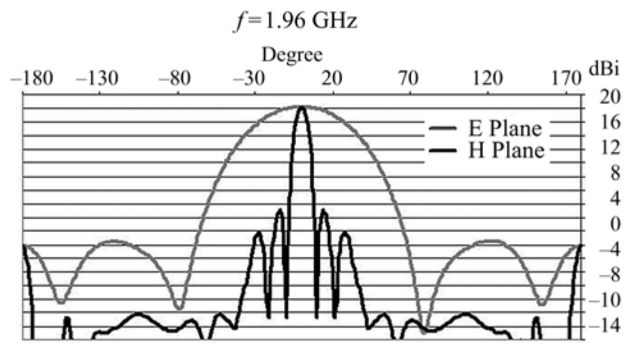

Fig. 19 Radiation patterns at 1.96 GHz

3.2 Antenna in horizontal polarization

This antenna uses only one-dimensional structures in TM polarization; the feed ports and the metallic rods must be in a horizontal distribution (Fig. 18).

The influence of different parameters such as the multisource technique is the same as the last antenna. This antenna offers a significant gain going until more than 18 dB and a very good sectoral cover in the azimuth plane.

Figure 19 represents the radiation patterns at 1.96 GHz; we obtain a radiation beamwidth in the E plane of 62° and a very directive pattern in the H plane. Maximum directivity reaches 18.2 dBi. The side lobes are correct since being lower than −16 dB compared to the principal lobe in the E plane.

The return loss showed on Figure 20 is very sufficient.

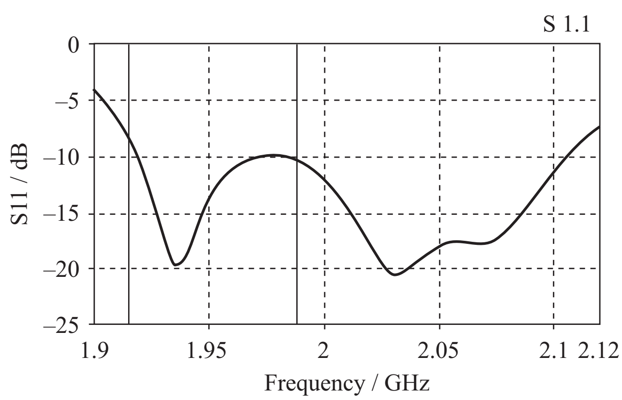

Fig. 20 Return loss

Combining horizontal and vertical structures, it is possible to create dual polarized EBG as it will be detailed in the next section.

3.3 Antenna with dual polarization

3.3.1 Presentation

We describe a dual polarized sectoral antenna design operating around 2.5 GHz with a 16 dB gain

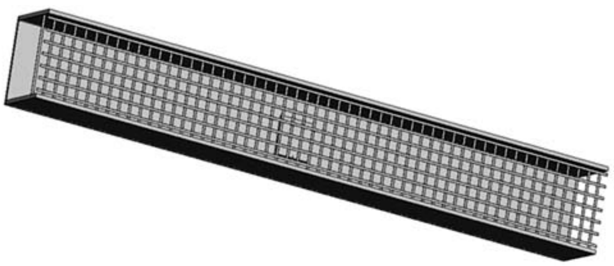

Fig. 21 Geometry of the dual polarized sectoral antenna

and a half power beamwidth of 60° in the horizontal plane.

This antenna is able to radiate either in vertical or horizontal polarization with a sectoral pattern in azimuth. The basic configuration of the proposed antenna is illustrated in Figure 21.

The two EBG materials are working on orthogonal polarizations; they are thus transparent for each other.

3.3.2 Dimensions and results

The metallic EBG structure in vertical polarization made up of 7 rods of 3 mm with 15 mm periodicity and 0.5 mm thickness each one, in horizontal polarization the EBG structure is composed of 53 rods. The EBG structure has the same dimension and periodicity in horizontal and vertical distribution.

The simulated ground plane has the same size as the structure i.e. 800×110 mm^2.

The EBG structure has thus 60.5 mm height compared to the ground plane.

This antenna is excited by a single patch, which is fed by two coaxial probes for controlling and switching between horizontal and vertical polarizations.

The results are presented below; Figure 22 shows the Directivity versus frequency for horizontal and vertical polarization.

Figure 23 and Figure 24 represent the radiation patterns for the two cases respectively at 2.51 GHz. In the vertical plane the radiation is directive with low side lobes, in the horizontal plane these figures present an interesting sectoral pattern of 60°.

The cross polarization is quite low, never exceeds −15 dB (Fig. 25).

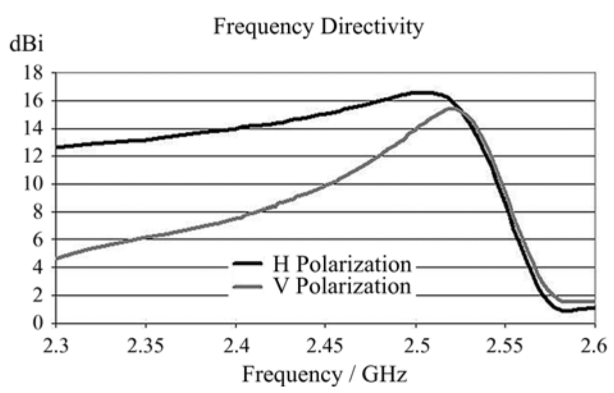

Fig. 22 Directivity evolution for the two cases

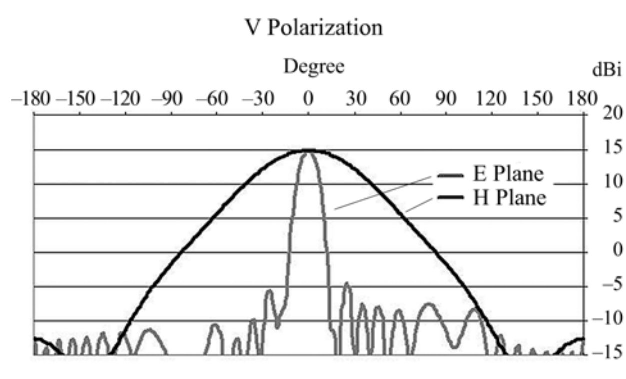

Fig. 24 Radiation patterns at 2.51 GHz

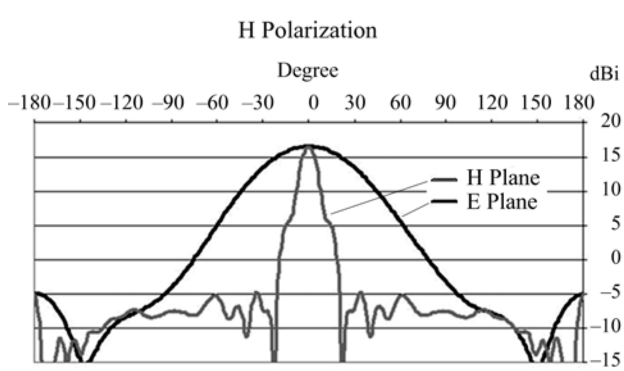

Fig. 23 Radiation patterns at 2.51 GHz

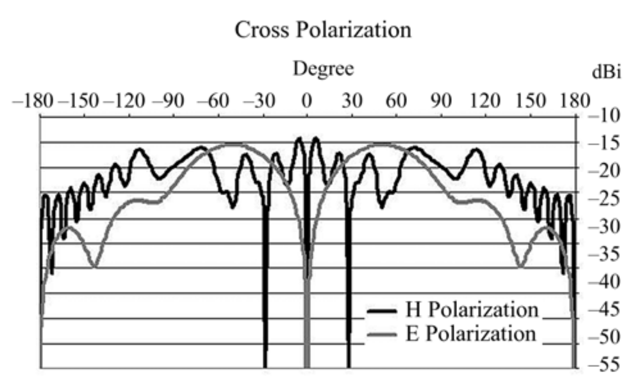

Fig. 25 Cross Polar in V and H polarization

4 CONCLUSIONS

This manuscript proposes an original application of EBG materials to build sectoral antennas with several advantages. They have low side lobes, present a reduced obstruction….

The study of EBG materials showed that their electromagnetic properties allow antennas design with significant gain. We showed that planar structures can be adapted to obtain structures whose radiation is sectoral >60° in the azimuth and directive in the elevation plane.

Moreover, the use of the multi-source technique enabled us to increase the gain and the band-width at the same time. It was also possible, by combining the two structures independently designed, to obtain an antenna operating in both polarizations with a sectoral pattern in azimuth. These antennas are compatible for radiations with circular polarization [9].

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Metalne EBG sektorske antene za različite polarizacije. Svrha je rada proučavanje i proračun antena za bazne stanice koje sadrže metalne materijale s elektromagnetskim zapornim pojasevima (EBG). Cilj je bio ostvariti i proučiti nove koncepcije metalnih EBG-antena koje bi radile sa širokim oblikom dijagrama zračenja, tj. s kutnom širinom snopa od barem 60 stupnjeva. Uporaba metalnih struktura nov je pristup koji nudi industrijskim partnerima mogućnost smanjenja troškova i ujedno im olakšava tehnologiju izrade. Visoka impedancija metalne strukture omogućuje uporabu samo jednog sloja žica, kao i izradu kompaktnije antene u odnosu na onu s dielektričnom strukturom

Ključne riječi: metalna EBG-antena, sektorski dijagram zračenja, tiskana antena, vertikalna polarizacija, horizontalna polarizacija, dvojna polarizacija.

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Received: 2008-02-10
Accepted: 2008-04-29