COMPARISON OF BANDGAPS AND BANDWIDTHS OF MUSHROOM-TYPE EBG SURFACE AND STRIP-TYPE SOFT SURFACES WHEN USED AS NARROW GROUND PLANES

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ABSTRACT

The purpose of this work is to compare different strip-type soft surfaces and mushroom-type EBG in different aspects. Firstly, strip-type soft surfaces are characterized in the same way as electromagnetic bandgap (EBG) surfaces, i.e. in terms of dispersion diagrams and bandgaps. Secondly, they are also studied in terms of the bandwidth of a system related performance parameter; when they are used as narrow ground planes to reduce back radiation. To this aim a vertical electrical source is used. The results are in both cases compared with those of mushroom-type EBG surface. The strip loaded soft surface can be realized with periodic via holes (like in patch-type EBGs), in this case the via period is used as an extra parameter to optimize the bandgap. Also, the placement of the vias either in the centre or at the edge of the strip, both for strips and for mushroom-type EBGs has been investigated. The lateral position moves the bandgap to lower frequencies, thus giving smaller period of the surface for a given frequency. When the surfaces are used as small (1.5λ) ground planes both, strips and mushroom have similar performances for TM case (vertical polarization) whereas the strip surface has larger bandwidth for TE case (horizontal polarization).

Key words: soft surface; EBG; bandgap; back radiation.

1. INTRODUCTION

The concept of soft and hard surfaces was introduced to the antenna community in 1998 [1, 2]. The use of these surfaces has been related to their ability to suppress (soft case) or to enhance (hard case) wave propagation along the surface. The basic implementations of them are corrugations in a metal plate or metal strips on a grounded dielectric slab. However, the classical corrugated surface is heavy and expensive to manufacture, and the strip-loaded surface supports undesired surfaces waves bound to the slab which destroy the performance.

The need of via holes in the realization of soft surfaces by using metal strips on a grounded slab, to provide well-defined bandgaps proposed in [3], was inspired by the patch-type Electromagnetic Bandgap (EBG) surfaces ("mushrooms") in [4]. EBG surfaces have the capability of stopping surface wave propagation, so they are in this sense, similar to soft surfaces. However, soft surfaces have this property only in one direction of propagation. The relations between EBG surfaces and soft/hard surfaces are discussed in more detail in [5].

The quality of the EBG surface is often measured in terms of the size of the bandgap whilst soft surfaces are most often characterized in terms of the bandwidth of a system related performance parameter, such as cross polarization, back lobes or side lobes. For instance, the soft surface was used as a ground plane to reduce back radiation of small antennas like helical, spiral, etc. in [8], [9]. The purpose of this work is to characterize and compare both type of surfaces in the two ways, i.e. in terms of their bandgaps and also comparing how well these two different stop surfaces perform when they are used as narrow ground planes to reduce back radiation.

2. BANDGAPS OF PLANAR SOFT SURFACES

The different realization of both soft surfaces and patch-type EBG surfaces are plotted in Fig. 1. In this work we will study three types of stop surfaces; strips with walls (B and D)and vias (C and E) and patch-type EBG (F and G). We investigate also both lateral and central locations of the vias on the strips, and on the patches of the mushroom surface.

2.1. Bandgap of strip loaded surfaces

A planar version of soft surfaces can be made with a structure formed by strips printed on a grounded dielectric slab with the strips short-circuited to the ground plane along one edge with vertical metal walls, thereby resembling horizontal corrugations. The geometric parameters are therefore derived from those of the corrugated surface. In particular, we let the width of the strips

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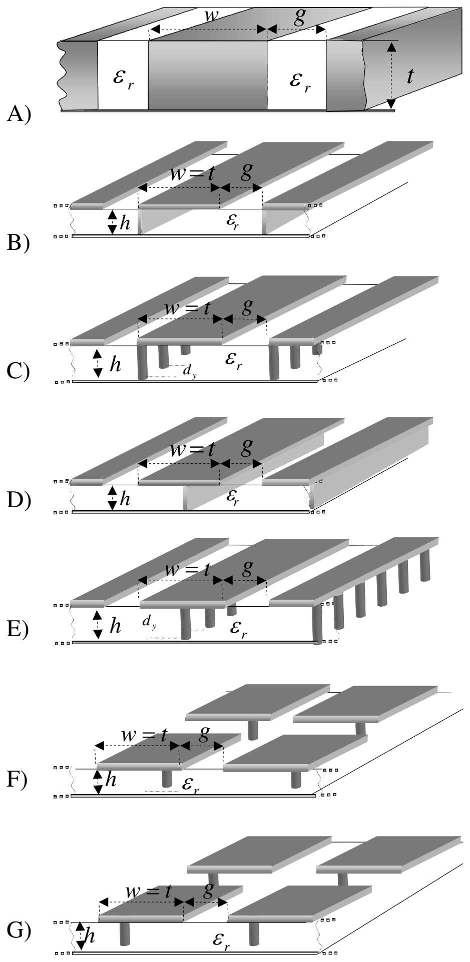

Figure 1. Different realizations of STOP surfaces

be equal to the depth of the corrugations, i.e. $0.25\lambda_{0\epsilon_r}$ and we choose permittivity ϵ_r = 4.4 and the gap size g= $0.035\lambda_{0\epsilon_r}$.

Solid lines in Fig. 2 show how the thickness of the substrate affects the bandgap. This horizontally corrugated surface has a much lower profile than the vertically corrugated surface. When the thickness of the dielectric substrate is increased, the bandgap increases as well. The lower cutoff frequency decreases as the thickness increases because the effective width of the strip becomes larger whilst the end frequency of the bandgap is not affected. On the other hand, the thickness of the substrate can be reduced and the bandgap is still large.

Although the previous surface is thin, the lateral walls are expensive and not compatible with planar manufacturing. Therefore we now replace the vertical walls by pins or metalized via holes. The structure is now periodic in two dimensions. The dashed lines in Fig. 2 show the bandgap behaviour as a function of the via periodicity for a fixed thickness of the dielectric substrate ($0.06\lambda_{0\epsilon_r}$).

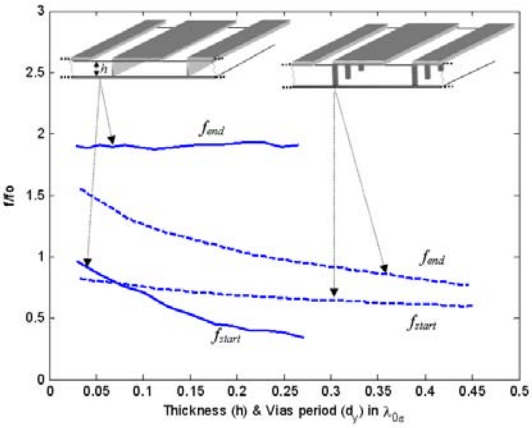

Figure 2. The solid lines show the start and stop frequencies of the bandgap as a function of substrate thickness (h) for strips with lateral walls ($w = 0.25\lambda_{\epsilon_r}$, $g = 0.035\lambda_{\epsilon_r}$,$\epsilon_r = 4.4$) an the dashed lines as a function of vias period (d_y) for strips with lateral vias ($w = 0.25\lambda_{0\epsilon_r}$, $g = 0.035\lambda_{0\epsilon_r}$, $h = 0.06\lambda_{0\epsilon_r}$, $\epsilon_r = 4.4$).

Here, we see that now the bandgap appears at lower frequencies than for the previous case, since the periodic vias represent an equivalent inductive loading, or in other words, the effective width of the strip becomes larger. At the same time, the relative bandgap size is considerably reduced. Therefore, vias can be used to reduce the physical size of the soft surface elements for a given frequency of operation, with the drawback of a smaller bandgap size.

It is also possible to make these soft surfaces by placing vias or wall in the center of the structure (see Fig. 1 C and E). The effect of thickness and vias period is for the central position case is similar [7]. However for the same strip width, the structure with central vias or wall has bandgaps at higher frequencies.

2.2. Comparison with patch-type EBG

We compare now the mushroom-type EBG surface (geometries F and G in Fig. 1) with the strip-loaded surface with respect to propagation in the soft direction of the latter. Therefore, the mushroom size will be chosen to be the same as the strip width, i.e. $0.25\lambda_{0\epsilon_r}$. Naturally, we will choose the via period for the strips to be the same as for the mushroom surface, i.e., $0.285\lambda_{0\epsilon_r}$.

The dispersion diagram when the vias are located at the edge of the patch is plotted together with the corresponding strip in Fig. 3. The solid lines are for mushrooms and the dashed lines for strips. We observe that the start and end frequencies are almost the same for both cases

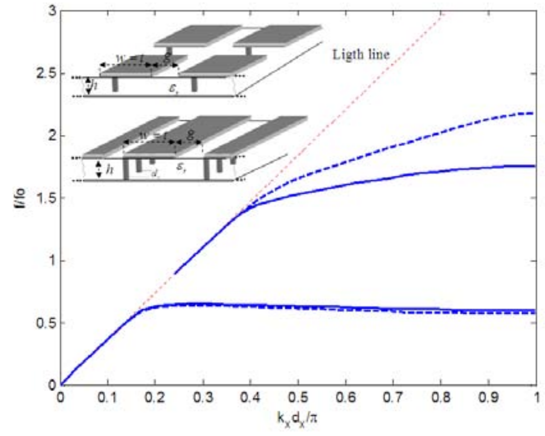

Figure 3. Dispersion diagram of mushroom type EBG surfaces (solid-lines) and strips-loaded surfaces (dashed-lines), both with lateral vias. ($w = 0.25\lambda_{0\epsilon_r}$, $g = 0.035\lambda_{0\epsilon_r}$,$\epsilon_r = 4.4$).

	f_{start}	f_{end}
Strips	$0.637f_0$	$0.93f_0$
Mushrooms	$0.650f_0$	$0.924f_0$

Table 1. Start and stop cutoff frequencies for the bandgaps of EBG-Mushroom surfaces and Strips-loaded surfaces, both with lateral vias.($w = 0.25\lambda_{0\epsilon_r}$, $g = 0.035\lambda_{0\epsilon_r}$, $\epsilon_r = 4.4$).

(see Table 1 for numerical values), so consequently the bandgaps are very similar.

If now we analyze the case where the vias are moved to the center of the strips and the mushrooms, the dispersion diagrams are as in Fig. 4. The strip width is also in this case $0.25\lambda_{0\epsilon_r}$. The numerical values that define the bandgap are presented in Table 2. If we compare Table 1 and 2, we can conclude that for the same dimensions a change in vias position from the middle of the strip to the edge of it, means a bandgap at lower frequencies. Moreover, in strip-loaded we can increase the period of vias and reduce strip width (w) and have a bandgap at the same frequency.

	f_{start}	f_{end}
Strips	$0.858f_0$	$1.15f_0$
Mushrooms	$0.815f_0$	$1.079f_0$

Table 2. Start and stop cutoff frequencies for the bandgaps of EBG-Mushroom surfaces and Strips-loaded surfaces, both with central vias. ($w = 0.25\lambda_{0\epsilon_r}$, $g = 0.035\lambda_{0\epsilon_r}$, $\epsilon_r = 4.4$).

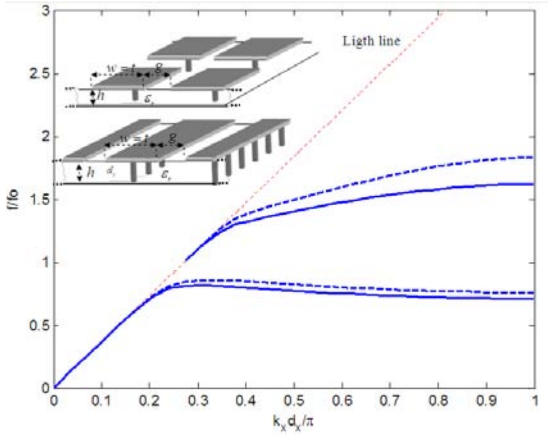

Figure 4. Dispersion diagram of mushroom type EBG surfaces (solid-lines) and strips-loaded surfaces (dashed-lines), both with central vias. ($w = 0.25\lambda_{0\epsilon_r}$, $g = 0.035\lambda_{0\epsilon_r}$, $\epsilon_r = 4.4$).

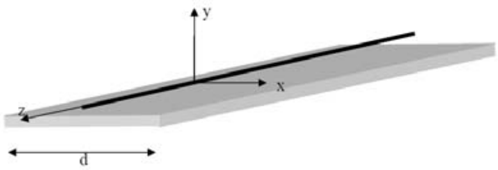

Figure 5. Description of the problem: infinitely long ground plane of width d and a vertically polarized electric filament current

3. GROUND PLANES RESULTS

In the second part of this work we study and compare how well the different stop surfaces perform when they are used as narrow ground planes to reduce back radiation. For this study we choose a vertical short electric dipole over a narrow ground plane. The vertical dipole excites the TM case with respect to the surface normal. In order to simplify we assume that the ground plane is infinitely long. We also expand the vertical dipole to an infinitely long current filament that is located along and parallel with the ground plane (Fig. 5). The current filament has constant phase and a current direction that is transverse to the filament direction and vertical to the ground plane. This means that we study a two-dimensional (2D) case, except for a possible longitudinal periodicity of the surface, that will be present for the mushroom surface and strip-loaded surface with vias. The chosen system performance parameter is the relative power radiated into the region behind the ground plane, i.e. for $180° < \phi < 360°$ in a coordinate system where the ground plane coincides with the XZ-plane and the normal to the ground plane is in $\hat{y}$-direction.

When the frequency of operation is chosen to make the different surfaces ideally soft, the behavior for vertical polarization (TM case) should be similar to a Perfect Magnetic Conductor (PMC). We will therefore use the PMC as a reference case in the calculations for TM case.

A parameter for measuring the back radiation has to be defined. We choose the relative power on the rear side of the half plane defined by the extended ground plane, i.e.

$$\Gamma_{back} = \frac{power\ \ radiated\ \ for\ \ 180^\circ < \phi < 360^\circ}{total\ \ power\ \ radiated\ \ for\ \ 0^\circ < \phi < 360^\circ} \tag{1}$$

Results for the different structures will be plotted as a function of frequency when the ground plane width and surface structure dimensions are fixed in terms of wavelengths at a certain reference frequency f_0. This is defined for each structure and corresponds normally to the frequency at which the theoretical bandgap starts.

We also use the back radiation of ideal PEC and PMC ground planes as references calculated in [6].

3.1. Strips with lateral wall

We study first the "horizontal" corrugations as in section 2.1, i.e. corrugations in which the $\lambda/4$ dimension is achieved horizontally instead of in the vertical dimension. The thickness is not related to the wavelength so it can theoretically be as thin as wanted. The w dimension has to be $\lambda_{0\epsilon_r}/4$.

The symmetrization of the structure with respect to the radiating source has been done as shows Fig. 6. This avoids asymmetrical radiation patterns.

The results for strips with a lateral solid wall are showed in Fig. 7. This Figure contains two graphs corresponding to two different ground plane sizes: $1.5\lambda_0$ and $4\lambda_0$. The abrupt reduction of back radiation at a specific frequency is clear in both cases, moreover, the larger the ground plane size means the larger the number of periods of the periodic structure and therefore, the structure will be closer to the ideal infinite one. Obviously, there is a difference in the back radiation level due to the size.

In the same graph the back radiation for an ideal PMC ground plane of both sizes are included.

3.2. Strips with lateral vias

Vertical walls are still expensive from the manufacturing point of view, therefore, the next step was again to replace those walls by vias. Now the structure has a double periodicity. The effect of vias period in bandgap has been proved to allow element size reduction in the study of the

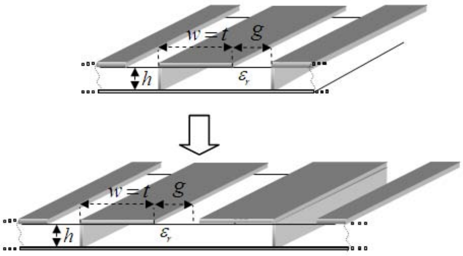

Figure 6. Symmetrization of the horizontal corrugations

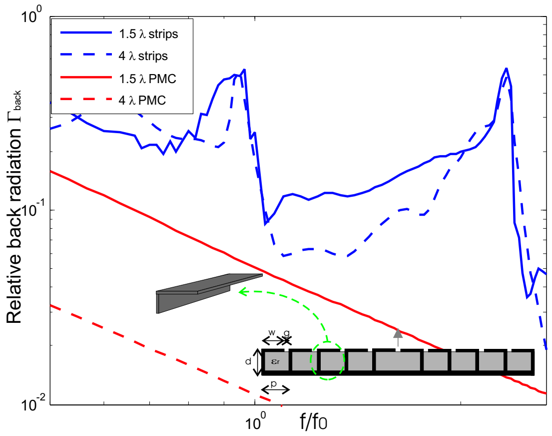

Figure 7. Back radiation of strip with lateral wall for two ground plane sizes: $1.5\lambda_0$ *and* $4\lambda_0$ *(with* $\epsilon_r = 4.4$*,* g*=* $0.1\lambda_{0\epsilon_r}$*,* d*=*$0.1\lambda_{0\epsilon_r}$*,* w*=*$0.25\lambda_{0\epsilon_r}$*).*

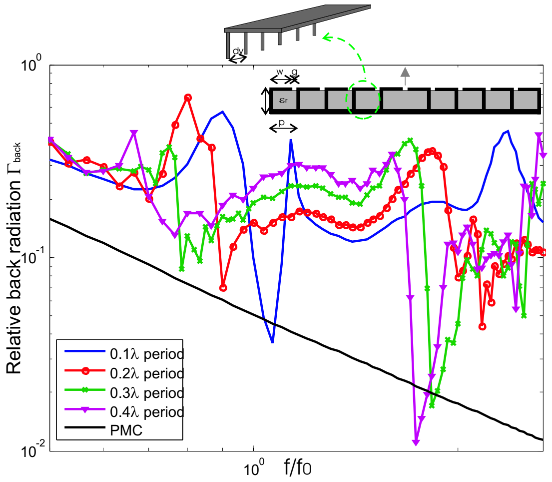

Figure 8. Strip with lateral vias for different vias period ($\epsilon_r = 4.4$*,* w*=* $0.25\lambda_{\epsilon_r}$*,* g*=* $0.1\lambda_{\epsilon_r}$*,* d*=*$0.1\lambda_{\epsilon_r}$*). Ground plane size1.5*λ_0

ideal infinite structure in previous Section 2.1. When the vias period increases, the bandgap moves towards lower frequencies and it suffers a size reduction.

These effects can also be observed in this particular application as shows Fig. 8. The larger the period, the smaller the bandgap in addition to a displacement towards lower frequencies. This result is in good agreement with the previous theoretical study.

Although the back radiation level inside the bandgap is higher if the vias period increases this is due to the reduction in the ground plane electrical size and does not mean a worse performance of the surface.

3.3. Mushrooms comparison

Now a mushroom type EBG is used as narrow ground plane. The comparison with the equivalent strip case is presented. This means that the vias period d_y in the case of strips is the mushroom EBG period. Two different types of mushroom structures have been studied now: with vias at the edge and in the center.

Fig. 9 and 10 contain the comparison between mushroom-EBG surface and equivalent loaded strip with vias for a $1.5\lambda_0$ ground plane size both for the vias at the edge and in the center cases. The performance of both geometries is similar in both cases.

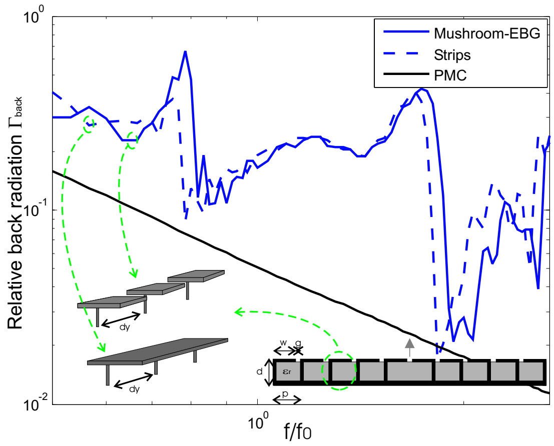

Figure 9. Bandwidth of ground plane with mushroom-EBG surface and loaded strips both with lateral vias (ground plane size $1.5\lambda_0$).(with $\epsilon_r = 4.4$, $g= 0.1\lambda_{0\epsilon_r}$, d=$0.1\lambda_{0\epsilon_r}$, w=$0.25\lambda_{0\epsilon_r}$,$d_y = 0.35\lambda_{0\epsilon_r}$)

Also for this application the same conclusion as in the theoretical study can be derived: when the via is placed at the edge of the mushrooms instead of in the center, the bandgap goes towards lower frequencies. This implies a size reduction as it had been previously suggested.

Although for vertical polarization both loaded strips and mushroom type EBG have approximately the same performance, the soft surface made of loaded strips has an advantage due to its anisotropy: for the horizontal polarization it behaves as a PEC, therefore cancelling also this polarization, whilst the mushromm-type EBG behaves as a PMC inside the bandgap for both polarizations and thus, the horizontal polarization is not cancelled. This has been simulated using a longitudinal source type ($\hat{z}$ direction in Fig. 5) over both the soft surface made with strip with vias and the mushroom EBG type ground plane. These results for a ground plane of $4\lambda_0$ and with vias placed at the edge, appear in Fig. 11. The strip-loaded surface has the same behavior in all frequencies (PEC) whilst in the performance of mushroom-EBG surface there is a frequency range with high back radiation: this is the bangap when the surface behaves as PMC.

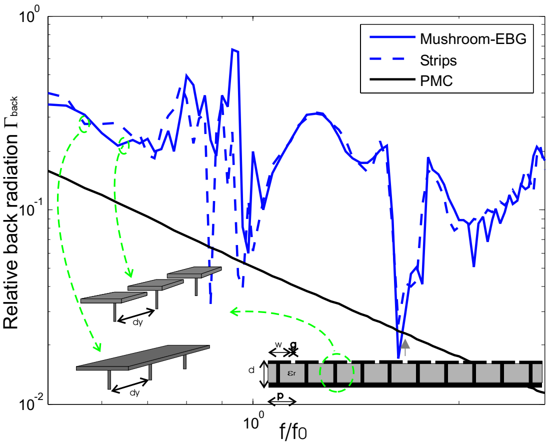

Figure 10. Bandwidth of ground plane with mushroom-EBG surface and strips both with central vias (ground plane size $1.5\lambda_0$).(with $\epsilon_r = 4.4$, $g= 0.1\lambda_{0\epsilon_r}$, d=$0.1\lambda_{0\epsilon_r}$, w=$0.25\lambda_{0\epsilon_r}$,$d_y = 0.35\lambda_{0\epsilon_r}$)

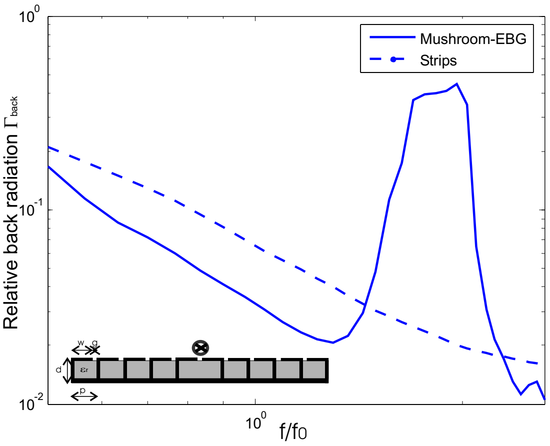

Figure 11. Bandwidth of ground plane with mushroom-EBG surface and strips both with lateral vias (ground plane size $4\lambda_0$).(with $\epsilon_r = 4.4$, $g= 0.1\lambda_{0\epsilon_r}$, d=$0.1\lambda_{0\epsilon_r}$, w=$0.25\lambda_{0\epsilon_r}$,$d_y = 0.35\lambda_{0\epsilon_r}$). Longitudinal polarization.

4. CONCLUSIONS

Planar versions of soft surfaces can be made with strip-loaded surface with metal walls or pins. Their bandgaps vary both with the thickness of the substrate and the vias period. Increasing the thickness the size of the bandgap also increases whilst replacing the vertical wall by periodic via holes, the bandgap region moves to lower frequencies (as a function of that period) but also its relative size decreases.

Dispersion diagrams of mushroom surfaces and those of strip-loaded surface with metalized via holes and corresponding dimensions are very similar. Furthermore, for strip-loaded surfaces with vias we can use the period of the vias to move the bandgap towards lower frequencies, therefore reducing physical size which is advantageous. Moreover if we change vias position from the center to the edge, the bandgap appears at lower frequencies, thus giving smaller period of the surface for a given frequency.

Similar properties are found when these surfaces are used as small ground planes. However, although strips and patch-type EBG have similar performances for TM case (vertical polarization), the strip surface has larger bandwidth for TE case (horizontal polarization).

In conclusion, lateral vias position are useful to reduce size of strips and mushrooms and in the strip case, the optimization of the vias period allows a further reduction. For narrow ground plane applications the strips offers an advantage for TE case (horizontal polarization).

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