

Parametric Study of Mushroom-like and Planar Periodic Structures in Terms of Simultaneous AMC and EBG Properties

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Abstract. In the paper, the parametric analysis of a mushroom-like and a planar metollo-dielectric periodic structure with square unit cell and metallic patch is presented. First, the angular stability for different unit cell settings was studied. Second, restrictions for simultaneous behavior as artificial magnetic conductor (AMC) and electromagnetic band gap (EBG) are briefly discussed. Finally, main differences between the mushroom-like and the planar structure are specified and conclusions are formulated.

Keywords

Artificial magnetic conductor, electromagnetic band gap, mushroom and planar structure, angular stability.

1. Introduction

Recently, an intensive interest in periodic structures in antenna engineering can be observed. Periodic structures enable to design low profile antennas and improve the performance of planar antennas by the suppression of surface waves [1]. In a certain frequency range, metallo-dielectric periodic structures can behave as an artificial magnetic conductor (AMC) or as an electromagnetic band gap (EBG) surface. AMCs reflect electromagnetic waves at a frequency called “AMC point” with a zero phase shift. On the other hand, EBGs do not support surface waves in a frequency interval called the “band gap”. In many cases, the AMC point is required to be within the band gap region. Unfortunately, the design of such a structure is rather difficult.

In the paper, restrictions for simultaneous AMC and EBG properties of the conventional mushroom structure and of the planar one (without shorting pins) with square unit cell and square metallic patch (Fig. 1) are defined. A similar study was published in [2]; however the parametric analysis presented in the paper considers both the influence of the unit cell size and the patch size at the same

time. Moreover, the particular emphasis was put on the angular stability of AMC behavior.

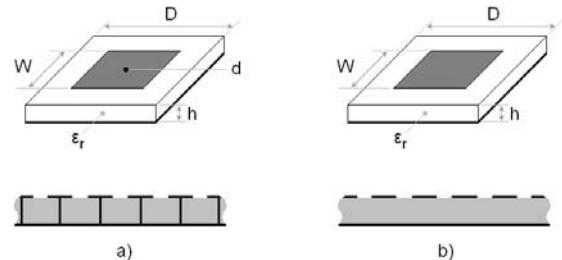


Fig. 1. The mushroom structure with vias (a), the planar structure without vias (b). Upper figures show the unit cell, lower figures show the cross-section.

2. Dispersion Diagram and Reflection Phase Computation in CST MWS

A structure with a forbidden frequency band (no electromagnetic wave propagation is possible), can be fully characterized by its dispersion diagram. The dispersion diagram is a graphical representation of the wave vector in dependence on frequency and gives us information about the position of pass-bands and stop-bands in the frequency spectrum. The reflection properties of a structure can be obtained by computing its reflection diagram, which is the graphical representation of the frequency dependence of the phase shift between the incident and reflected wave. The reflection phase diagram differs for different angles of the wave incidence and a frequency shift of the AMC point can be observed. This frequency shift is called the angular stability of the structure. Due to this, it is necessary to compute the reflection phase diagram of the structure for normal and also off-normal wave incidence.

In this work, the commercial finite difference time domain (FDTD) solver CST Microwave Studio (CST MWS) was used for both dispersion diagram and reflection phase computation of the considered structures. To verify the results from this tool, the dispersion diagram and reflection phase characteristics of the periodic structure

from the open literature [2] was computed and next compared to the results obtained by different technique and measurement. The structure under consideration is a planar periodic metallic array with the unit cell shown in Fig. 1b. The values of parameters are: unit cell size $D = 9.1$ mm, patch size $W = 6.6$ mm, dielectric substrate height and relative permittivity $h = 1.13$ mm and $\epsilon_r = 2.2$, respectively.

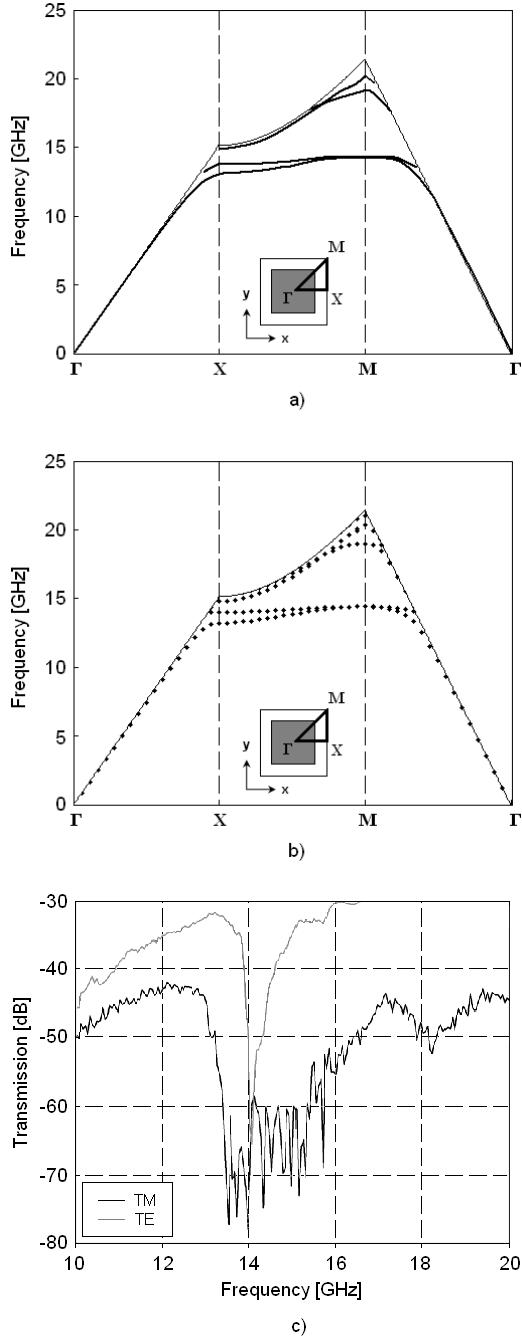


Fig. 2. EBG performance of the planar periodic structure from Fig. 1b and parameters described in the text: dispersion diagram from [2] computed by MoM (a), dispersion diagram computed in CST MWS (b), experimental verification [2] (c).

The dispersion diagram of the structure, computed using the method-of-moment (MoM) and the measured EBG performance [2], together with the dispersion diagram calculated in CST MWS, are depicted in Fig. 2. As well as the dispersion diagram from the literature [2], the one computed in CST MWS predicts a band gap in x-direction (Γ -X) for both TM and TE polarized waves at 14 GHz. The experimental verification [2] shown in Fig. 2c agrees with the theoretical results.

The MoM-computed and measured [2] reflection phase diagram for the same structure as described above and normal wave incidence, is drawn in Fig. 3a, whereas the one obtained using the frequency domain solver of CST MWS is depicted in Fig. 3b. Results from CST MWS are in excellent agreement with the measurement and show the zero reflection phase point at 13.8 GHz.

Presented results confirm the credibility of the dispersion diagram and reflection phase computation of periodic metallic structures in CST Microwave Studio.

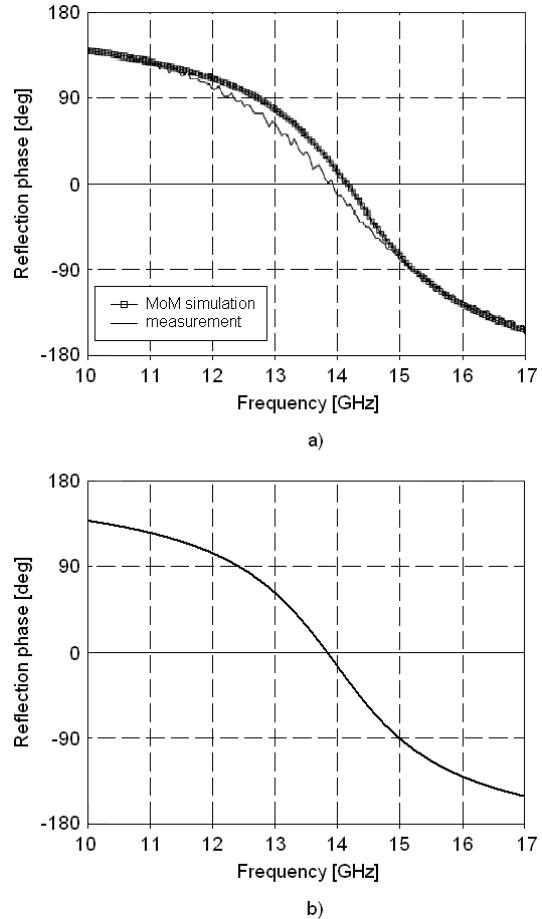


Fig. 3. AMC performance of the planar periodic structure from Fig. 1b and parameters described in the text: MoM-computed and measured reflection phase diagram from [2] (a), reflection phase diagram computed in CST MWS (b).

3. AMC Characteristics of Mushroom and Planar Structures

In this section, the AMC behavior of mushroom and planar structure from Fig. 1 is discussed. The structures differ in the presence or absence of vias only. In one hand, the AMC bandwidth (the frequency interval, within the reflection phase is larger than -90 deg and smaller than +90 deg) and the other hand the angular stability of the considered structures for different unit cell settings is studied.

Based on computer simulations, there is only a slight difference between the mushroom and the planar AMC characteristics for TM polarized waves at the non-perpendicular incidence. This is caused by the presence or the absence of vertical vias. In Fig. 4a, reflection phase diagram of the planar structure for $h = 5.08$ mm, $\epsilon_r = 1.0$ and the patch size versus the unit cell size ratio $W/D = 0.97$ is depicted. Because of the square unit cell with 8-fold symmetry, reflection phase curves for the perpendicular wave incidence are identical for both the TE polarization and the TM one. The structure exhibits a poor angular stability (for TM wave incidence primarily).

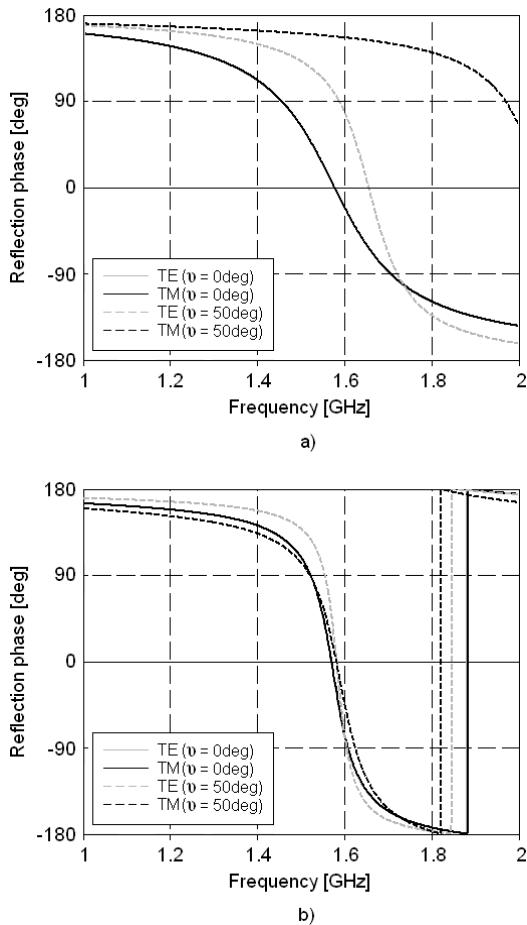


Fig. 4. Reflection phase curves of the planar structure: $h = 5.08$ mm, $\epsilon_r = 1.0$, $W/D = 0.97$ (a), $h = 5.08$ mm, $\epsilon_r = 6.15$, $W/D = 0.50$ (b).

The angular stability can be improved by decreasing the patch size vs. the unit cell size ratio. However, the unit cell size is limited, and its maximum is given by the onset grating lobe condition [2]

$$D_{max} = \frac{c}{f(\sin \nu + 1)} \quad (1)$$

where c is the light velocity in free space ($c = 3 \cdot 10^8$ m·s $^{-1}$), f is the frequency and ν is the angle of incidence.

If the maximum allowed cell size is reached, and the angular stability of the AMC surface does not meet the requirements, the permittivity of the dielectric substrate should be increased. Then, the shape of the TM reflection phase curve becomes flat. Choosing the correct patch size vs. unit cell size ratio, almost the zero frequency shift of the AMC point for an arbitrary angle of wave incidence can be achieved (Fig. 4b). The negative effect of the increasing dielectric slab permittivity and the decreasing patch versus unit cell size ratio is the narrower AMC bandwidth.

To give us comprehensive information about the angular stability of the studied structures, the so-called BIA (frequency band versus incidence angle) maps [3] of the AMCs with the same parameters as in Fig. 4 are depicted in Fig. 5 and Fig. 6.

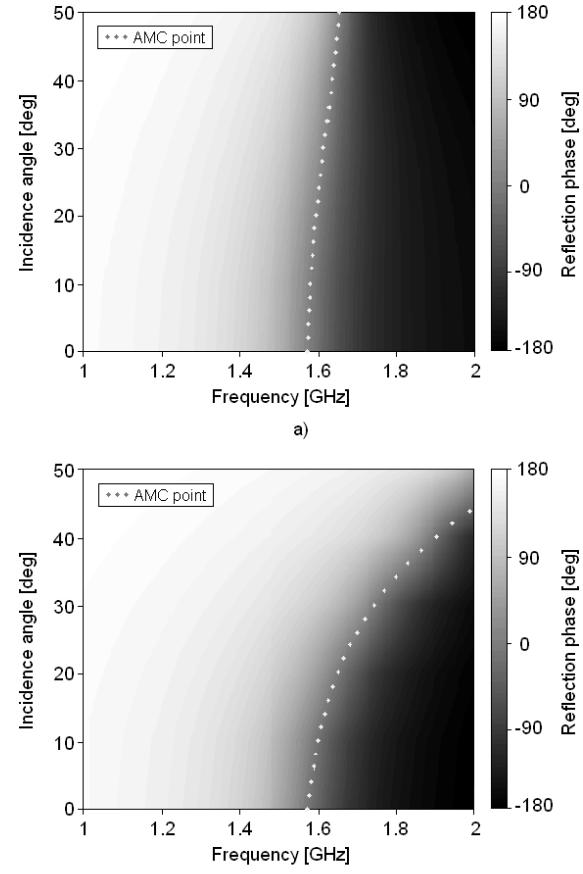


Fig. 5. BIA map of the planar structure from Fig. 4a: TE polarization (a), TM polarization (b).

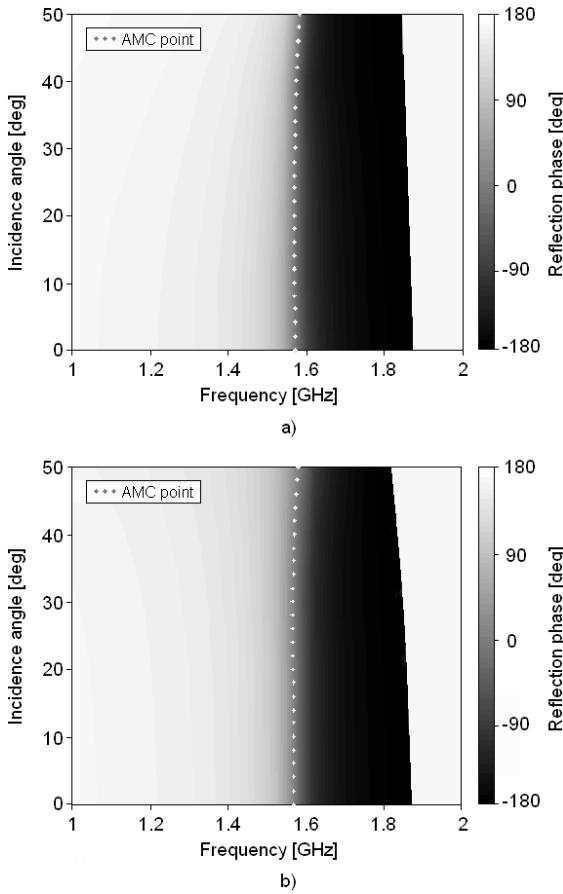


Fig. 6. BIA map of the planar structure from Fig. 4b: TE polarization (a), TM polarization (b).

The substrate thickness does not significantly influence the AMC behavior of the studied structures. Generally, thick AMC surfaces exhibit worse angular stability. However, reflection phase curves for both TE polarization and the TM one are flatter, which leads to larger AMC bandwidth.

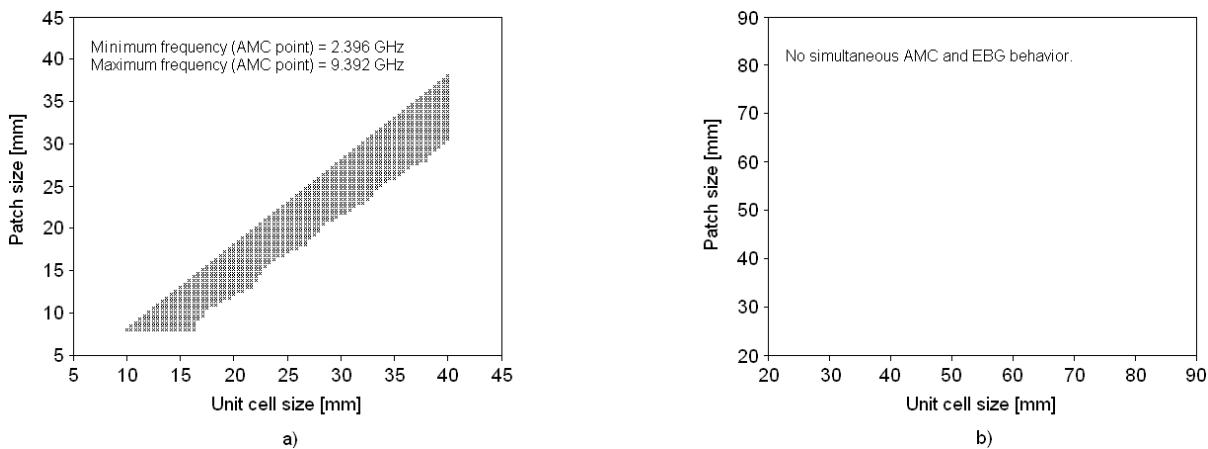


Fig. 7. Simultaneous AMC and EBG characteristics ($h = 5.08 \text{ mm}$, $\epsilon_r = 1.0$, diameter of the vertical via $d = 2.0 \text{ mm}$): mushroom structure (a), planar structure (b).

4. Simultaneous AMC and EBG Characteristics of Mushroom and Planar Structure

In this section, the simultaneous AMC and EBG behavior of a mushroom structure and a planar one are briefly described. The effect of the substrate thickness and the dielectric constant was investigated to establish the restrictions. For different substrates, the reflection phase diagram and the dispersion diagram were computed in 28 points for a given range of the unit cell and the patch size. In order to achieve the desired resolution, the points were interpolated in Matlab. Shaded areas in Fig. 7 to Fig. 9 show the unit cell size and the corresponding patch size having the AMC point within the band gap.

Generalizing the results of computer simulations, the following conclusions can be formulated:

- The mushroom exhibits simultaneous AMC and EBG behavior for a large patch size versus unit cell size ratio only. In the planar case, the AMC point is located within the band gap for W/D about 0.5.
- For the mushroom, a thick substrate with low permittivity is needed. For the planar structure, a thin substrate with high permittivity can be used.
- Because of the thin substrate with high permittivity and the smaller patch versus unit cell size ratio, a planar structure can exhibit a better angular stability than a mushroom one.
- The large cell size of a planar structure is very uneconomical.
- The main disadvantage of the planar structure is a very narrow simultaneous AMC and EBG bandwidth (typically about 2%), whereas for the mushroom structure is up to 30%.

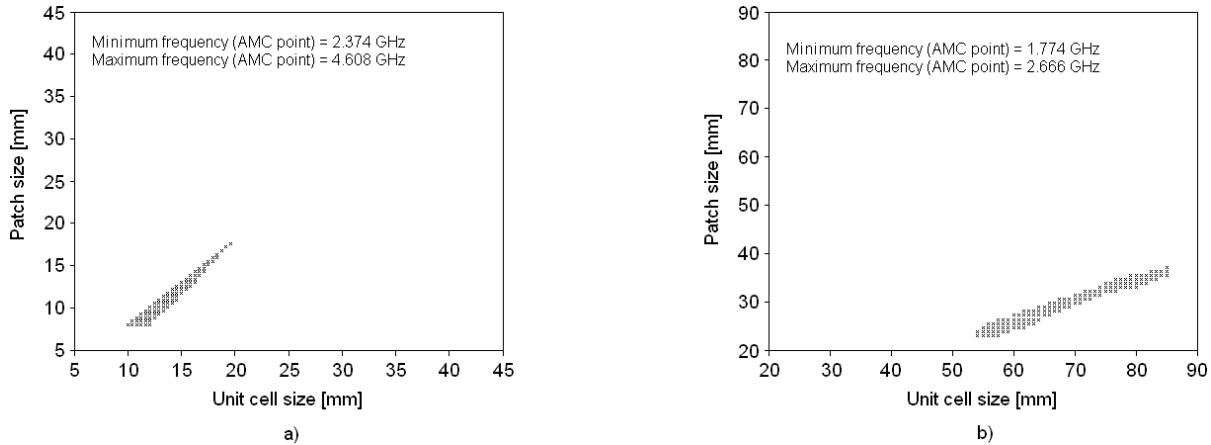


Fig. 8. Simultaneous AMC and EBG characteristics ($h = 5.08$ mm, $\epsilon_r = 4.4$, diameter of the vertical via $d = 2.0$ mm): mushroom structure (a), planar structure (b).

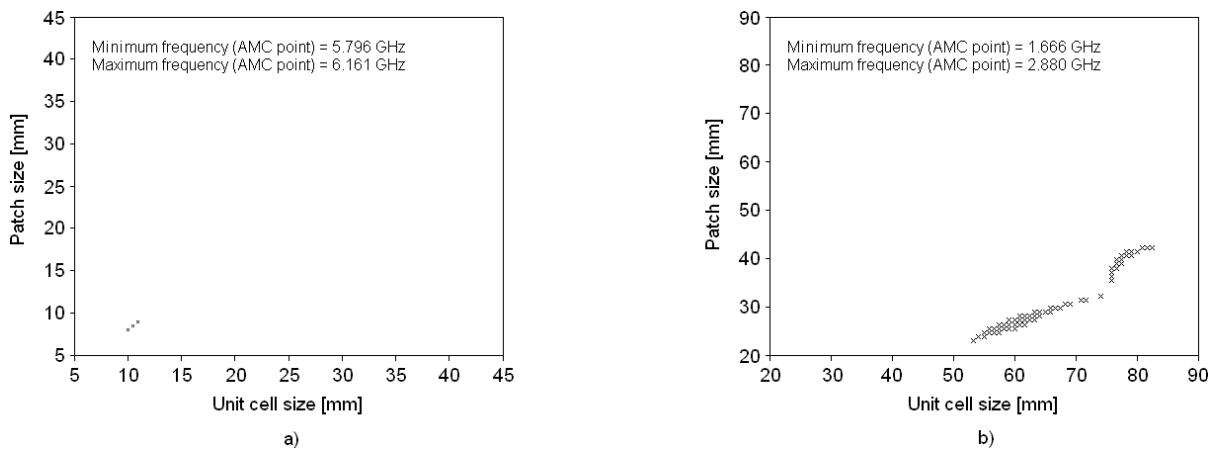


Fig. 9. Simultaneous AMC and EBG characteristics ($h = 2.54$ mm, $\epsilon_r = 4.4$, diameter of the vertical via $d = 2.0$ mm): mushroom structure (a), planar structure (b).

5. Conclusions

In the paper, a parametric analysis of the mushroom-type structure and the planar periodic one was presented. The effect of the patch size and the unit cell size on the simultaneous AMC and EBG behavior was discussed, and the influence of the substrate height and the permittivity was studied. Possible unit cell arrangements for better angular stability were described. The very narrow AMC and EBG bandwidths are the main limitation in the planar case. Results imply that patches with more complicated geometry (designed by genetic algorithms, for example) are needed.

Acknowledgements

The research described in this contribution was financially supported by the Czech Grant Agency under the grants no. 102/07/0688 and 102/08/H018, and by the research program MSM 0021630513. The research is a part of the COST project IC0607 ASSIST.

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