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A New High Impedance Surface Featuring Several Electromagnetic Band-Gaps

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Abstract – A high impedance surface featuring several electromagnetic band gaps is introduced. The surface is devised in microstrip technology and its properties are studied by electromagnetic simulation. We consider some variations of the geometry in order to extract information on the influence of geometrical elements on the position and width of the different frequency stop bands. We outline possible applications, including a switched surface or sensors.

Keywords: Microstrip, High Impedance Surface, Electromagnetic Band Gap, Electromagnetic Simulation.

I. INTRODUCTION

Microstrip technology may be used to build 2D periodic surfaces by impressing a periodic pattern on one of the faces of a board. Such structures are able to conduct surface Bloch waves. Some geometries have been devised that do not allow propagation of surface waves in certain frequency bands, called electromagnetic band gaps (EBG's). A very well-known one is Sievenpiper's "mushroom" structure [1,2], which has a rectangular 2D period and one period (unit cell) consists of a rectangular metallic patch placed at the center of the cell, connected at its center to the ground plane through a metallic via. The structure presents an EBG that stops the propagation of the fundamental mode. As the lack of propagation inside the EBG can be described by the existence of a large impedance, this property has been chosen to give the name of the structure, which is known as a high impedance surface (HIS).

Several attempts have been made to enhance the favorable properties of the "mushroom" HIS. For example, additional degrees of freedom in design can be achieved by allowing for eccentric positions of the via inside the surface occupied by the metallic patch within a 2D period [3].

The properties of HIS are best studied by full-wave simulation, which is a time- and resource-consuming process. Therefore, circuit models have been proposed that allow for a rapid design but with a certain degree of approximation [4,5]. The models can be applied to the suppression of the fundamental mode of propagation, but indicate, with approximation, also the existence of several EBG's in some circumstances.

In this paper, we propose a new structure for a HIS. The unit cell is square shaped and it contains a square patch as described before, with the via displaced in a direction parallel with one of the sides of the period. This direction is parallel to the x axis in our notation. The patch is surrounded by a square contour, having a certain width and containing or not a via. If the second via exists, its center, together with the center of the first one determines a line that is parallel to the x direction.

The "mushroom" HIS has a shielded counterpart [5], which is obtained by placing a metallic plane above the structure. The space in between this metallic plane and the ground plane of the microstrip board determines an inhomogeneous parallel plate waveguide (PPW). The lack of homogeneity stems form the presence of two layers with a certain thickness, one made of dielectric and one consisting of air and from the very thin plane containing the metallic pattern described above. Both Sievenpiper's HIS and PPW's based on it proved very useful in various applications [6..9].

The HIS we are introducing here presents several EBG's, so it may be used as a multiband filter. If intended for use as a single filter, the HIS may play the role of a bandpass or bandstop filter. We determine the position of the EBG's by means of full-wave simulation [10] in view of finding the dispersion diagram (DD) [11]. We are interested in the propagation properties of electromagnetic surface waves along one of the directions parallel with the sides of the patches, so that we calculate the DD only for the ΓX edge of the first irreducible Brillouin zone in the 2D wavenumber space. This corresponds to propagation along the x direction defined above.

We consider several variations of the HIS described above. As interest on electronically switched or tunable surfaces emerged lately [12..14], we also outline a possibility to alter the basic configuration in order to obtain a switched surface by

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using electronically controlled diodes. We present the DD's in the two cases corresponding to the two states of the diodes: biased and unbiased. In this way, we find the modifications of the EBG's that are determined by the change of state of the diodes.

II. ELECTROMAGNETIC BANDGAPS OF THE BASIC HIGH IMPEDANCE SURFACE

The initial configuration of the HIS we have introduced and tested is presented in Fig. 1. The following dimensions have been chosen: D_x=D_y=2.5 mm, a=0.35 mm, b=0.6 mm, c=1.1 mm and t_1=1.6 mm. The vias have equal radii, of 0.1 mm and are centered at points (–0.15 mm, 0) and (0.85 mm, 0) respectively. These dimensions are kept throughout all the rest of the simulations, unless specified differently. The structure is scalable so that the results obtained here can be extrapolated to other dimensions and frequency bands. The dielectric constant of the substrate of the microstrip circuit board has been ε_1=3.5.

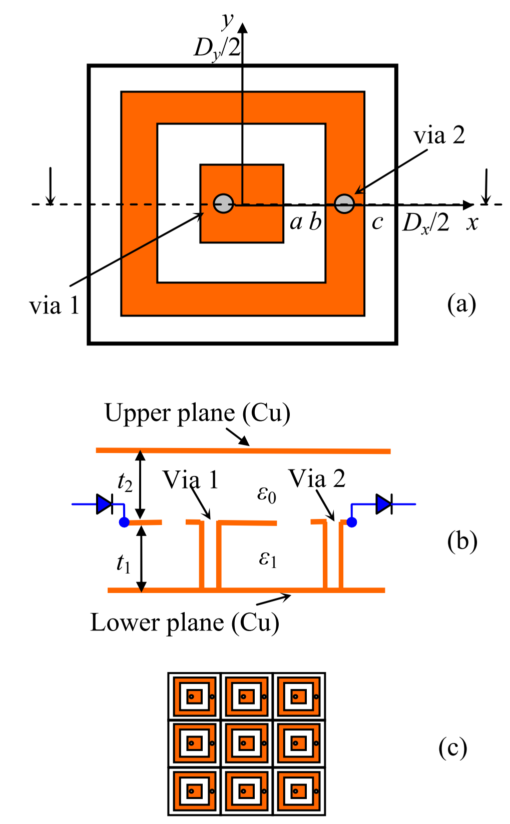

Fig. 1. (a) Basic cell: top view. (b) Side view. (c) HIS.

The most interesting feature of the DD is the presence of three EBG's, Fig. 2. The DD in Fig. 2, featuring the first eight propagation modes, has been obtained for an air space t_2=0.1t_1. Normalized wavenumbers $k_x D_x = \frac{2\pi}{\lambda_x} D_x$ [rad] are represented on the horizontal axis. The CAD model of the main period is reported in the inset of the figure, without the upper metallic plane. The light line (LL) is also represented on Fig. 2. Modes corresponding to points above the LL are evanescent while those corresponding to points below the LL propagate. Nevertheless, we calculate the EBG widths regardless of the character of the modes. If only propagating modes would have been taken into account, the first two EBG widths, corresponding to lower frequencies, would have resulted larger.

We have repeated the experiment for two other distances between the patches and the upper metallic plane: t_2=0.3t_1 and t_2=0.5t_1. The positions in frequency of the EBG's and their widths are reported in Table 1. While the widths of EBG1 and EBG2 diminish with the increase of the air layer thickness, the width of EBG3 first increases, then decreases. The behavior of EBG1 is consistent with the prediction of circuit models devised for the EBG of the "mushroom" structure [4]. The behavior of higher frequencies EBG's need more sophisticated models in order to be predicted. This may be subject of future work.

Table 1. Position and widths of the EBG's

	t_2=0.1 t_1	t_2=0.3 t_1	t_2=0.5 t_1
f_{m1} [GHz]	6.67	7.84	8.17
f_{M1} [GHz]	11.88	12.22	11.97
BW1 [GHz]	5.22	4.39	3.80
f_{m2} [GHz]	15.00	17.47	17.99
f_{M2} [GHz]	28.79	24.59	21.15
BW2 [GHz]	13.79	7.13	3.16
f_{m3} [GHz]	44.17	44.34	44.50
f_{M3} [GHz]	46.18	46.89	45.54
BW3 [GHz]	2.01	2.55	1.04

The graph in Fig. 2 indicates that the HIS behaves like a multiband bandstop filter. It may also be used as a bandpass filter e.g. in the range of frequencies in between the upper frequency of EBG1 and the lower frequency of EBG2.

Table 1 shows that favorable values for the EBG parameters are obtained for t_2=0.1t_1, so that this value should be used for simple filtering applications. However, we intend to test the structure for the case when electronic components, such as diodes, are mounted on the side of the board containing the patches. Therefore, in the next simulations, the larger value t_2=0.5t_1 has been chosen.

III. ELECTROMAGNETIC BANDGAPS FOR VARIATIONS OF THE BASIC HIS

The CAD model of the first variation we have considered is reported in the inset of Fig. 3: we have removed one of the sides of the shape that surrounds the patch. The DD is presented in Fig. 3. Only two EBG's are present. The first one is in the range [8.30 11.58] GHz, having a width of 3.28 GHz and the second one occupies the frequency range [18.31 21.07] GHz having a width of 2.76 GHz. By comparing these values with the last column of Table

1, we see that the parameters of the EBG's have been modified. This result should have been expected, as both the fringe capacitance between patches and the capacitances between the patch plane and the metallic planes have been modified.

The next two experiments involve the influence of the second via on the DD. The CAD model in the inset of Fig. 4 shows the absence of the second via combined with an extension of the hollow patch up to the sides of the unit cell, i.e. $c=D_x/2$. The consequence on the DD, presented in the same figure, is the disappearance of the EBG's, caused by the existence of a direct metallic path along the middle layer of the structure, which give rise to a TEM mode. If however the old value of c is used (the hollow patch surrounding the central one not extended to the bounds of the unit cell), two EBG's are obtained (Fig. 5): [17.84, 21.02] GHz (3.17 GHz width) and [44.82, 45.50] GHz (0.68 GHz width). This result will be used in devising a switched surface.

Finally some modifications less extended in the space of the unit cell have been tested: two small patches placed as shown in the insets of Figs. 6 and 7. The patches are 0.1 mm wide along the y axis and have a length of 0.3 mm parallel to the x axis. They are placed along the symmetry axis of the initial patches in the first case, while the second small patched is displaced by –0.5 mm in the y direction in the second case. Another distinctions stems from the fact that the second via has not been considered in the first situation and it is present in the second one. The EBG in the DD of Fig. 6 is between [33.10, 36.63] GHz, having a width of 5.53 GHz. The EBG's in Fig. 7 are [7.95, 11.84] GHz (3.89 GHz width); [17.93, 21.15] GHz (3.22 GHz width) and [44.57, 45.52] GHz (0.95 GHz width, not represented explicitly in the figure).

The simulation results presented above show that, with minor modifications of the original structure, a wide range of HIS's with various parameters of the EBG's may be constructed. A special attention worth the structures in Figs. 5 and 6. The small patches in Fig. 5 may be thought to model biased diodes, while these small patches are absent in Fig. 6, which can be thought as a situation modeling unbiased diodes. Therefore, by means of biasing diodes, the structures in the two figures can be switched. In a practical situation, the HIS's are of finite extent. The bias voltage may be applied between the input hollow patch and the output one, so that the series connection of diodes is connected to the supply voltage. This is the reason why we considered the situation when the second via in a basic cell is absent: otherwise the supply voltage source would have been short-circuited.

IV. CONCLUSION

We have introduced a HIS featuring three EBG's, which may be used as a multiband bandstop filter or as a bandpass filter. We have shown that the parameters of the EBG's can be modified by means of small geometric alterations of the original structure. We have shown that an electronically switched surface with interesting frequency related properties can be obtained from the original structure. Other applications like sensors can be easily devised based on the described structure.

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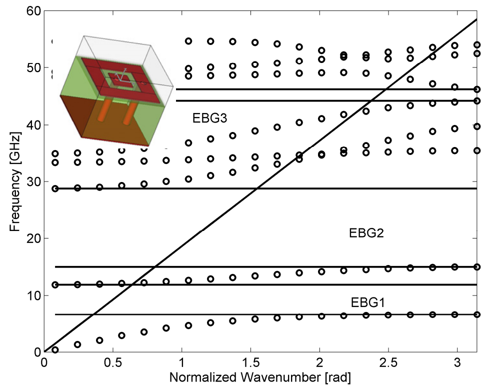

Fig. 2. DD for the basic structure.

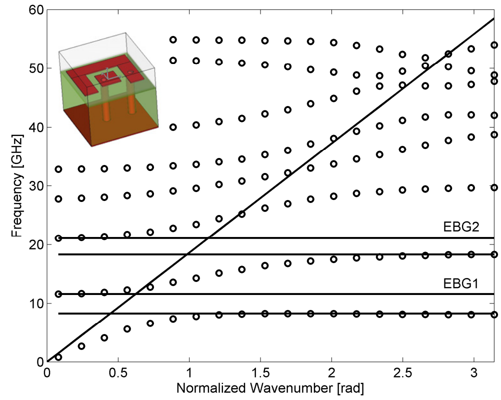

Fig. 3. DD – lower metallic path removed

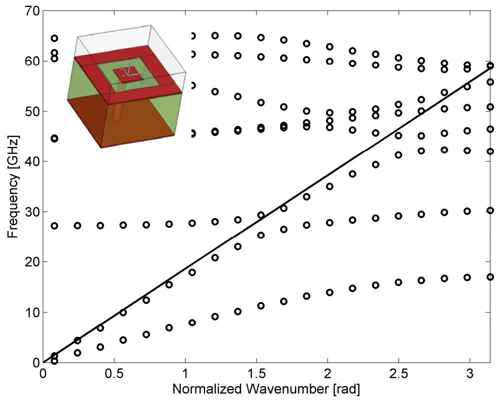

Fig. 4. DD – via 2 removed and external patch extended to the size of the unit cell.

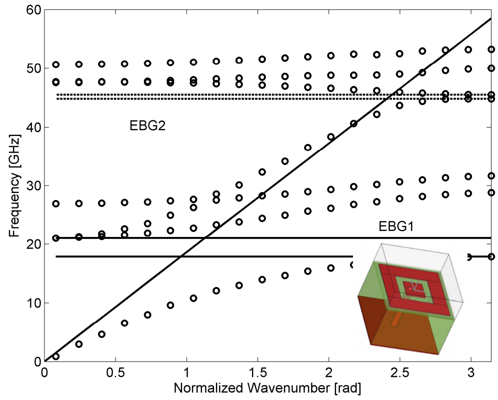

Fig. 5. DD – structure from Fig. 2 with via 2 removed.

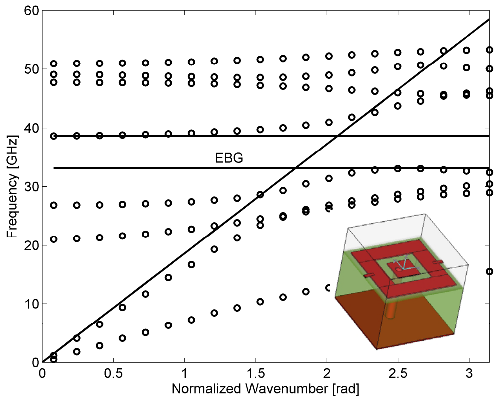

Fig. 6. DD – basic structure completed with biased diodes.

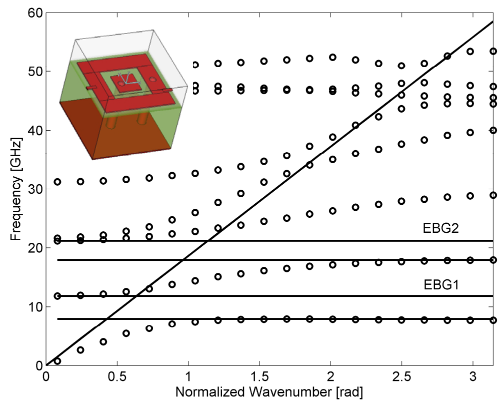

Fig. 7. DD – basic structure completed with two small patches.