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LTE Band Filtering Applications of a Fractal Based Frequency Selective Surface

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Abstract—In this paper we explore possibilities to tailor the transmittance of frequency selective surfaces (FSS's) realized on printed circuit boards (PCB's) to match design requirements by duplication of the metal pattern and fractalization. An FSS based on a novel unit cell structure is introduced, which is shown to exhibit angular stability up to 60° for TE and 45° for TM case. For the evaluation of the fine-tuning capabilities, a parametric study is performed. The configuration can be used for filtering in LTE, Wi-Fi and X band, commonly used in Automotive environment.

Keywords—frequency selective surface, fractal, LTE band, X band, angular stability

I. INTRODUCTION

The interaction of electromagnetic waves with thin material layers has important applications in various technical fields ranging from Microwaves, through Terahertz technology to Optics. Useful applications of the physical phenomena greatly depend on the material properties (dispersion, losses) of the media radiation is interacting with. In the case of electromagnetic waves, constitutive parameters are of interest.

Recent technological advances allowed for the creation of materials with properties that are not readily found in nature. The approach based on building periodic 3D or 2D structures, also named metamaterials, with spatial periods much smaller than the wavelengths of interest is widely used in this sense. If this condition is met, the materials respond to electromagnetic waves similarly to a bulk one, but with constitutive parameters that can be engineered as desired in the considered application. Frequency selective surfaces (FSSs) are obtained in the case of planar, periodic layers that interact with incident electromagnetic plane waves in meaningful way, by modifying various parameters of the wave such as amplitude, direction of propagation, wave front, phase, polarization etc. [1, 2].

Important applications of FSSs are obtained from a convenient design that controls the transmission, reflection and absorption coefficient. To name a few, spatial filters in transmission, selective reflectors, selective absorbers and

absorbers (devices that absorb incident electromagnetic energy in some frequency ranges and reflect the energy in other ranges) and radomes have been reported [1-3].

FSSs are resonant structures, so that generally they exhibit several narrow-band frequency intervals that can be exploited for application point of view. In order to obtain wide-band frequency responses, resonators must work on closely spaced frequencies or mutual coupling must be increased [3-5].

For FSSs implemented on PCBs, a large variety of metal patterns has been reported in the literature. Among them, patterns inspired from fractal paradigm proved to offer several interesting features overcoming some of the previously mentioned limitations. One can mention increased electrical length, allowing for miniaturization (i.e., decreasing the dimensions of the spatial period – unit cell with respect to wavelength), presence of a high number of resonances, insensitivity to polarization due to symmetry and operation in a large range of incidence angles [6-10].

In this paper, we consider a fractalized structure starting from a metal square with 4 additional squares created around the initial one. This might be considered the stop-band converse of the solution proposed in [4], which is additionally fractalized. The starting pattern for the unit cell resulted in an X band filter. To obtain a wide-band stop filter we duplicated the structure on the other side of the FR4 substrate in order to shift the resonance of the initial pattern by duplication. With the intention of obtaining a fractal, three additional metallic squares were added at each vertex of the initial structure, with the dimensions divided in half from the previous square component.

By geometrically iterating this structure, we obtained a pre-fractal structure with a lower notch frequency. Motivated by technological constraints, no more than three iterations can be implemented on an actual solution [11]. We then duplicated again the fractalized structure on the back side to obtain a wide-band band-stop filter. It resulted that, with this structure, filtering could be achieved within Wi-Fi and LTE bands.

The features of the band-stop filter and the angular stability have been assessed by performing parametric studies

in function of geometrical dimensions of the elements of the unit cell. Results have been obtained by simulation by means of a commercial EM solver [12].

The proposed structure, introduced above, is fully described in terms of substrate characteristics, periodicity and other geometrical dimensions in the next Section. The parametric study on the impact of varying geometrical dimensions of the elements of the unit cell and results on assessment of angular stability are reported in Section III. Conclusions are drawn in the last Section.

II. PRESENTATION OF THE PROPOSED STRUCTURE

A. Initial Structure

The initial design for the FSS has been based on the unit cell with a metal pattern represented in Fig. 1 - front view. The structure is built on a single-layer FR4 substrate ($\epsilon_r=4.3$, $\tan\delta=0.025$) with a thickness of 3.2 mm. The construction of the structure has started from modeling a copper square with the sides of 8 mm, positioned at the center of the unit cell.

In order to create the first iteration of the structure, the dimension used for the 1st square was divided by two; four additional squares were added, which were created around the first square with an overlap of $\frac{1}{4}$ of the new squares. Initially the design was created on a single side of the dielectric, the other side remaining empty [10]. This fractal structure is known as "T-square" and found application in antennas design [13]. In this paper, we investigate its behavior as a component of the unit cell of a FSS.

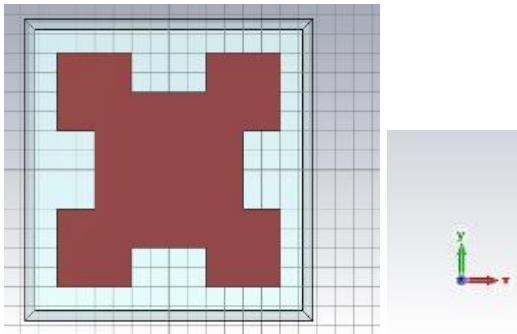


Fig. 1 One iteration, single layer

The FSS results are obtained by a 2D repetition of the unit cell in the d_x and d_y directions, both spatial periods having the dimension of 15 mm. The result calculated by means of [12] are reported in Fig. 2. Periodic boundary conditions and Floquet ports have been used for simulation. Our first target was to build a filter for the X band (8-12 GHz), commonly used in Automotive testing. With our structure, one notch appears in the frequency range of interest (at 8.83 GHz with attenuation level of 32.65dB), with a 10 dB stop – band in the frequency range 6.89 GHz – 9.06 GHz (2.97 GHz bandwidth), which covers part of the above-mentioned band.

In order to obtain a broadband filter, the same copper pattern (from Fig. 1) was also placed on the opposite side of the dielectric within the unit cell. The two structures exhibit the same geometrical footprint for observation from normal direction (the structure being symmetrical), as presented in Fig. 3. It has already been demonstrated that replicating the unit cell pattern of a single-face FSS built on a PCB on the other side of the board will have a significant impact on the transmission coefficient due to coupling [1]. Also, the

resonant frequency of the duplicated pattern is shifted with respect to the original one due to path difference for the wave [10].

In Fig. 4, the band-stop properties between 0 and 14 GHz of the structure in Fig. 3, obtained using [12] are reported for normal incidence. A broadband FSS with a 6.88 GHz bandwidth, in the frequency range 5.29 GHz – 12.17 GHz, and two notch frequencies at 5.72 and 11.48 GHz can now be noticed. The enlargement of the stop-band and the occurrence of an additional notch frequency demonstrate the effect of duplicating the pattern.

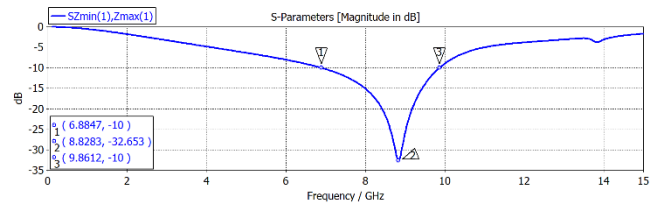


Fig. 2 Transmission coefficient for the FSS with unit cell in Fig. 1

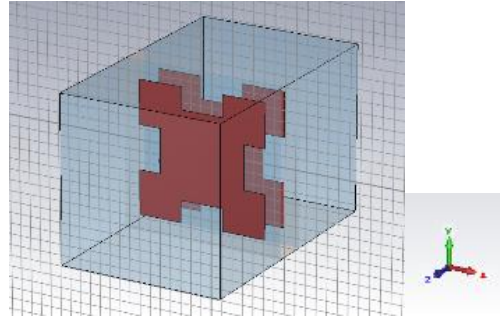


Fig. 3 One iteration, double layer

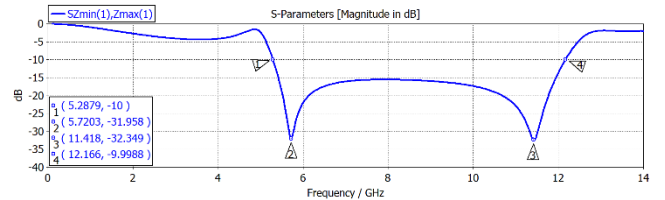


Fig. 4 Transmission coefficient for the FSS with unit cell in Fig. 3.

B. Fractalization

Fractalization of the structure consist in expanding the first created component by iterations, each iteration consisting of adding the previous component at the corners of the lastly generated pattern, with the dimensions further divided by two.

In order to respect this condition, in Fig. 5 three additional metallic squares were added in each corner of the structure with the dimensions divided by two from the previous square component.

In Fig. 6, the transmission coefficient for the FSS with the unit cell of Fig. 5 is reported. The initial notch was shifted to lower frequencies (from 8.83 to 7.01 GHz) with an increase of the notch level (-37dB) and a wider 10dB stop-band of the structure as compared to the one from Fig. 2, i.e. from 4.32 GHz to 8.07 GHz (3.75 GHz bandwidth – an increase of 26.3%).

The lower stop-band bound is shifted down by 2.57 GHz, while the upper bound is shifted down by 1.79 GHz. The stop-

band covers the part of the frequency range of Wi-Fi and LTE bands.

In order to further assess the performance of the structure, the same copper pattern was again added on the bottom side of the PCB. In Fig. 8, the stop-band properties of the structure in Fig. 7 are represented. The broadband behavior is this time obtained between 4.06 GHz and 9.57 GHz, with a 5.51 GHz bandwidth (10 dB stop-band), which again can be used for filtering inside Wi-Fi and LTE frequency bands. The first notch frequency of the previous iteration is shifted down by 1.12 GHz and the second notch is shifted down by 2.48 GHz.

The results reported in this Section clearly demonstrate that fractalizing an initial pattern of the unit cell is a solution for miniaturization, by shifting relevant filtering bands towards lower frequencies. Furthermore, duplication of the pattern introduces additional resonant frequencies that contribute to the enlargement of the stop-bands.

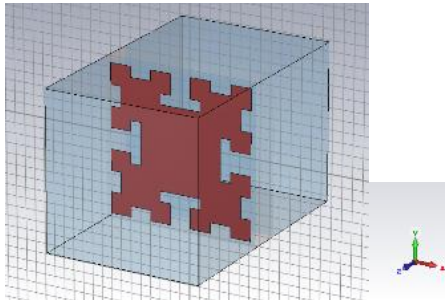


Fig. 5 Fractal two iterations, single layer

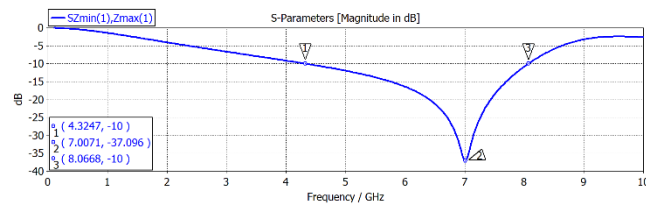


Fig. 6 Transmission coefficient for the FSS with unit cell in Fig. 5

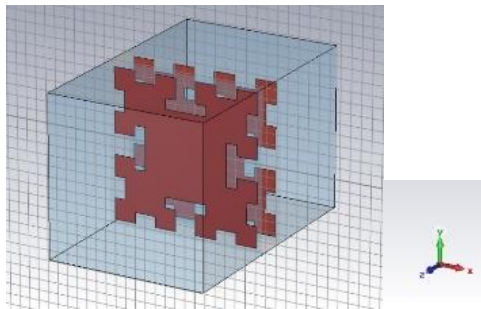


Fig. 7 Fractal two iterations, double layer

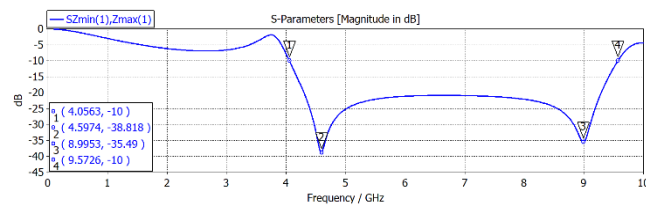


Fig. 8 Transmission coefficient for the FSS with unit cell in Fig. 7

III. PARAMETRIC ASSESSMENT

Design flexibility requires knowledge of the impact on the frequency response of the FSS of varying the parameters that

define the structure. Parametric studies have been carried out on the double layer structures in Fig. 3 and Fig. 7.

A. One iteration, dual layer

The first parametric study was performed on the impact of the FR4 substrate thickness, for the structure from Fig. 3. It consists of varying the parameter substrate thickness from 3.2 to 1.6 mm in steps of 0.4 mm. As reported in Fig. 9, changing this parameter to a lower substrate thickness, shifts the wide-band to higher frequencies, and also reduces the attenuation level.

This behavior can be motivated by the increase of mutual coupling between the two metal patterns that exist on the opposite sides the board by the modification of the path of waves through the dielectric.

Then, for the same structure (Fig. 3) we performed a study on angular stability by varying the angle of incidence from 0 to 60 degrees. The FSS is not sensitive to polarization of the incident wave due to the symmetric shape of the metal pattern of the unit cell. The results are plotted in Fig. 10 (TE mode) and Fig. 11 (TM mode). Despite the occurrence of various resonances for oblique incidence, the proposed FSS still behaves like a wide-band band-stop filter for incident TE waves. However, the response for TM mode incident waves is reasonable up to 45 degree. Improving this behavior will be subject of future work.

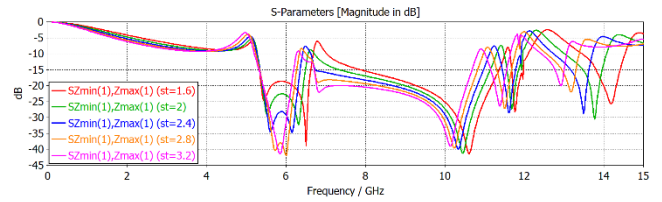


Fig. 9 Substrate thickness parametric study for the structure from Fig. 3

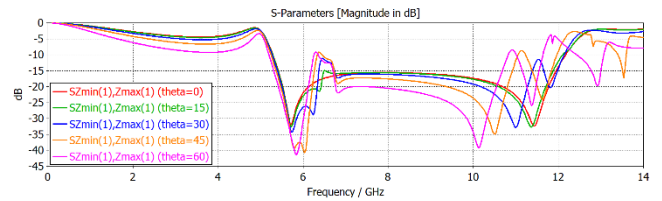


Fig. 10 Transmission coefficient at various angles of colatitude Theta (TE mode) for Fig. 3

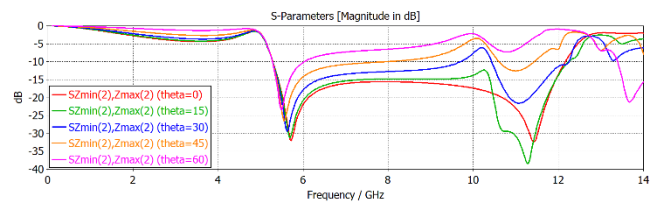


Fig. 11 Transmission coefficient at various angles of colatitude Theta (TM mode) for Fig. 3

B. Fractal two iterations, dual layer

The next parametric study was carried out on the FR4 substrate thickness, for the structure from Fig. 7. It consists again of varying the parameter substrate thickness from 3.2 to 1.6 mm with steps of 0.4 mm. As seen in Fig. 12, changing this parameter to a lower value is a convenient way to shift the wide-band to higher frequencies. The notch level is also enhanced.

The final parametric study (from Fig. 13) was performed to show the influence of the angle of incidence, for TE mode, Fig.7. The result demonstrates a good stability of the stop-band bounds.

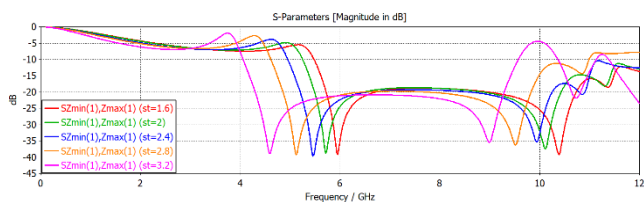


Fig. 12 Substrate thickness parametric study for the structure from Fig. 7

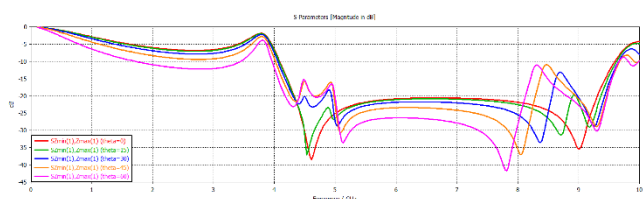


Fig. 13 Transmission coefficient at various angles of colatitude Theta (TE mode) for the FSS with the unit cell of Fig. 7

IV. CONCLUSIONS

In this paper we have illustrated how the position of the stop-band of a spatial filter relying on an FSS can be displaced towards lower frequencies by fractalization and how the bandwidth can be increased by duplicating the metal pattern.

It has been demonstrated that the proposed structure can work as an X band, Wi-Fi or LTE band-stop spatial filter.

The initial unit cell of the FSS built on FR4 substrate comprised a metal square on one side of the board. Fractalization consisted of replicating the initial square with sides reduced by one half at the vertexes of the initial square with 25% coverage and iteration of the process. The pattern has been replicated on the opposite face of the board.

The structure has been assessed by means of a commercial EM solver and characterized by the transmission coefficient. Wide-band band-stop behavior has been demonstrated for normal incidence and up to 60 degree in oblique incidence for TE waves and 45 degree for oblique incidence for TM wave.

In order to assess the flexibility of the proposed structure to meet various design requirements, e.g. control of notch frequencies and possibility to obtain a broad-band, band-stop filter, studies concerning the impact of modifying various parameters that define the unit cell have been performed and reported.

The proposed structure can be used in applications that require selective spatial screening, e.g. in Automotive industry.

Improvement of the behavior of the proposed structure under oblique incidence by a better control of the resonant frequencies constitutes subject of future work.

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