Fractal Based Frequency Selective Surface with Broadband Characteristics

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***Abstract*— A double layer fractal-based frequency selective surface (FSS) built on FR4 substrate exhibiting selectively: one notch, two notches and broadband characteristics is reported. The operation is demonstrated by computer simulation with a commercial solver. The FSS behavior is independent from angle incidence up to 60º for both TE and TM cases. For fine tuning a parametric study is performed.**

Keywords—frequency selective surface, fractal, broadband, angular stability.

I. INTRODUCTION

Frequency selective surfaces (FSS) are planar periodic structures that found applications in various important fields such as spatial filters, radomes, selective reflectors, absorbers etc. [1-4]. A cost-effective way of realizing FSSs is by etching a periodic metal pattern on one or both sides of a printed circuit board built on a substrate such as FR4. A well designed FSS with dipole type elements acts as a band-stop filter at its resonant frequency (working frequency) that accordingly decreases with the increase of the length of the dipole. Conversely, a slot type FSS acts as a band-pass filter [3].

An important issue in FSS design is miniaturization, i.e. designing unit cells with geometrical dimensions much smaller than the free space wavelength corresponding to the working frequency. A miniaturized unit cell in an FSS avoids the occurrence of the grating lobes for the transmitted wave [1]. Another important target of the FSS design in view of spatial filtering is to ensure a frequency response stable with respect to the incidence angle. The choice of the metal pattern in the unit cell has an important role in solving this problem. And still another goal is to design polarization insensitive surfaces, which can be achieved by considering unit cell structures that are invariant under 90º rotation [5].

Fractal geometric patterns have gained attention for application to FSS conception due to some favorable features such as efficient space usage, increase of electrical length of the pattern by iteration (and consequently decrease of the working frequency), multiband response and reduced sensitivity to incidence angle [4]. However, following space restrictions and technological limitations, in general the number of iterations used to construct the structure is smaller than 3. Sometimes, unit cells built by such a small number of iterations are described as having a "pre-fractal" structure.

Many practical achievements proved these concepts by using various shapes [4] such as composite cross spiral-H shaped element [5], Sierpinski gasket, Sierpinski carpet, Minkowski loop [6, 7], Minkowski island combined with fractal cross [8], Peano configurations [9] etc.

In this paper, initially, we consider a metal cross dipole situated on the diagonals of a square shaped unit cell. We consider the dipole as resulting from two symmetrically placed Vees and we iterate the Vees to obtain a pre-fractal structure. As expected, the cross dipole-based FSS features a notch frequency that inversely depends on its length. By geometrically iterating the Vee, we obtain a pre-fractal a structure with a lower notch frequency.

We then combine the pre-fractal with the initial cross dipole to obtain a wide-band band-stop filter. We determine the band of the filter in function of various geometrical parameters and we demonstrate that the response of the FSS to TE and TM waves that are incident from various angles presents a very good stability. Results are obtained by simulation by means of a commercial EM solver [10].

The proposed structure is introduced in the next Section. The parametric assessment of the filtering properties of the proposed FSS and its response to waves incident from various angles are reported in Section III. Conclusions are drawn in the last Section.

II. PRESENTATION OF THE PROPOSED STRUCTURE

A. Initial structure

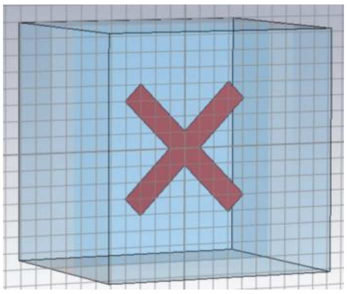
The initial unit cell, which is built on a FR4 substrate (ε_r=4.3, tanδ=0.025) with a thickness of 3.2 mm is presented in Fig. 1 (a). It consists of a cross pattern on a single side, the other side remaining initially empty. The arms of the cross are rotated by 45º, so that the two arms can achieve longer extension, within the same dimension of the unit cell. The geometrical dimensions of the first structure (case I) can be seen in the first row of Table 1, where w is the width of the arms and l is the length of the arms.

The FSS results by 2D repetition of the unit cell in the d_x and d_y directions, both of them being 15 mm. The magnitude of the transmission coefficient $|S_{21}|$ of a linearly polarized plane wave in normal incidence, calculated by means of [10] is presented in Fig. 2 (a). One notch appears in the frequency range of interest, at 9.02 GHz (19.48 dB attenuation). However, the attenuation can be further adjusted.

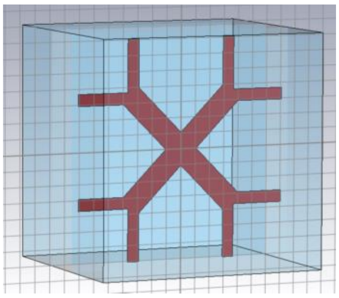
In Fig. 1 (b) we can see a first iteration of the fractal. The dimensions are those listed in the second row of Table 1 (case II), where w2 is the width of the arms of the first fractal and l2 is the length of the arms of the first fractal.

Its transmission properties are reported in Fig. 2 (b). The notch that appears in this case is shifted to lower frequencies (at 5.8 GHz) and it has an attenuation of 31.82 dB. So, by using a first iteration we can notice an increase of the notch attenuation.

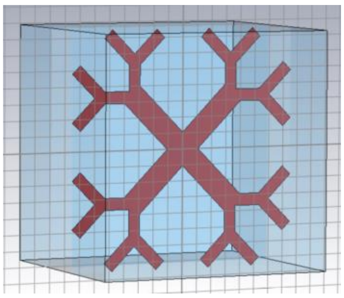
In Fig. 1 (c) we can see a second iteration of the fractal. Its dimensions are those listed in the third row of Table 1 (case III), where w3 is the width of the arms of the second fractal and l3 is the length of the arms of the second fractal. The transmission properties of this new structure are those reported in Fig. 2 (c). Two notches appear this time: one notch appears at 4.5 GHz (37 dB attenuation) and one at 8.75 GHz (20 dB attenuation). Thus, by using a second iteration we obtained an additional notch. The appearance of the second notch suggests that the structure can be turned into a broadband shield.



(a)

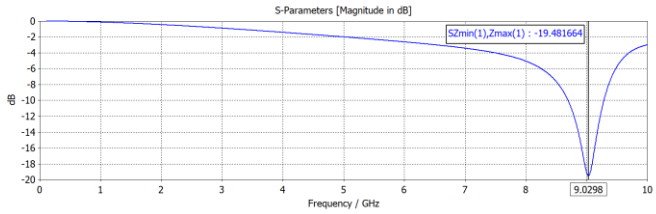


(b)

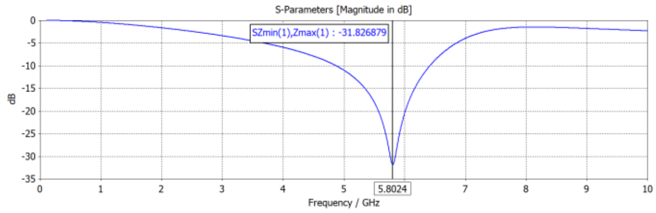


(c)

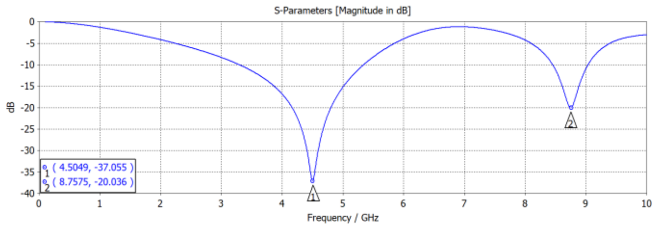
Fig. 1 Unit cell pattern (a) initial; (b) first iteration; (c) second iteration.



(a)



(b)



(c)

Fig. 2. Transmission properties of the structures from Fig. 1. The notation of the sub-figures is in correspondence.

Table 1 Geometrical dimensions for proposed structures (mm)

FSS	w	l	w2	l2	w3	l3	wb	lb
I	0.5	1	-	-	-	-	-	-
II	0.5	1	0.5	1.5	-	-	-	-
III	0.5	1	0.5	1	0.5	1	-	-
IV	1	1.8	-	-	-	-	1	1.8
V	0.5	1.2	0.6	0.8	0.4	0.5	1	1.8

B. Broadband structure

For further improvement of the structure, a copper pattern has been placed on the bottom side also. In Fig. 3 a second metallization is inserted on the other face, in particular another cross. These dimensions are reported in the fourth row of Table 1 (case IV), where wb is the width of the arms of cross from the back and lb is the length of the arms of the cross from the back. The transmission coefficient for this structure has also been simulated, but the results are not presented here.

We are interested now only in fractalization of one part of the structure. In Fig. 4 the geometry corresponding to the case of (1), two iterations on one part, and (2) no iterations on the other part (cross remaining unchanged) is reported. The dimensions for this last structure are reported in the fifth row of Table 1 (case V).

In Fig. 5 we can see the band-stop properties of the structure from Fig. 4. A broadband FSS is obtained between 4.11 GHz and 7.55 GHz, i.e. a 3.44 GHz bandwidth (-10 dB stop-band).

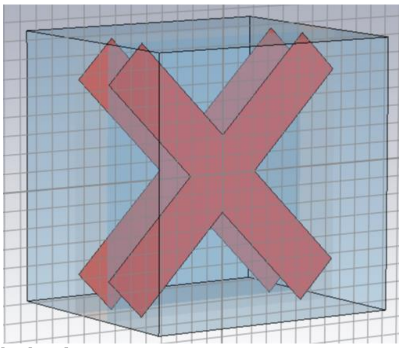


Fig. 3 Crosses on both sides

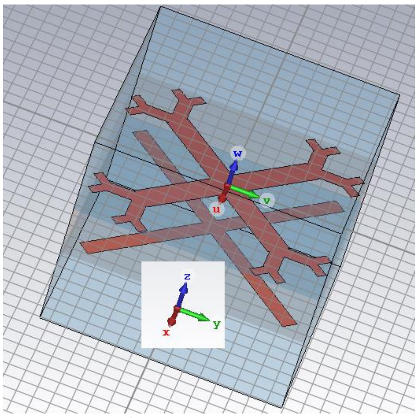


Fig. 4 Cross on one side; two-fractal iteration on the other side

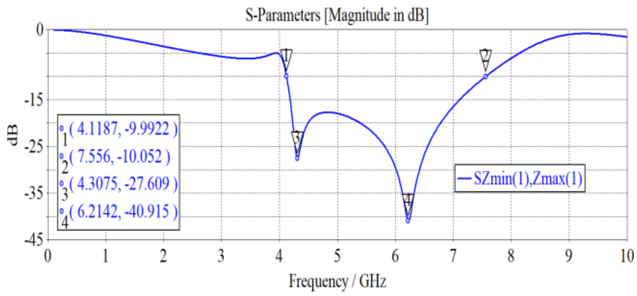


Fig. 5 Transmission properties of the structure from Fig.4

III. Parametric Study

Afterwards, we performed a parametric study on the structure from Fig. 4 in order to assess the sensitivity of the properties of interest with respect to the angle of incidence of the electromagnetic plane wave.

In Fig. 6 and Fig. 7 we can see a parametric variation of the colatitude angle (theta) with azimuth phi=0 (the azimuth is taken 0 due to the symmetry of the structure). This parameter has been varied in 5 steps between 0 and 60 degrees. We can see consistency for both modes (TE and TM) in this case and so the structure is insensitive to angular modification.

The bandwidths and the notch frequencies of a FSS can be tuned by varying some of the considered parameters of the structure.

A first parametric study is undergone for the structure from Fig. 1 (c) (with copper on only one side, and two iterations for fractalization). The effects of varying the width “w” between 0.2 and 0.8 in linear steps of 0.2 can be observed in Fig. 8.

Increase of the width shifts the first notch towards higher frequencies (from 4.32 GHz to 5.28 GHz and changes the attenuation from 33 dB to 37 dB). This modification also shifts the second notch in the same manner (from 8.6 GHz to 9.8 GHz and from an attenuation of 16 dB to 21 dB).

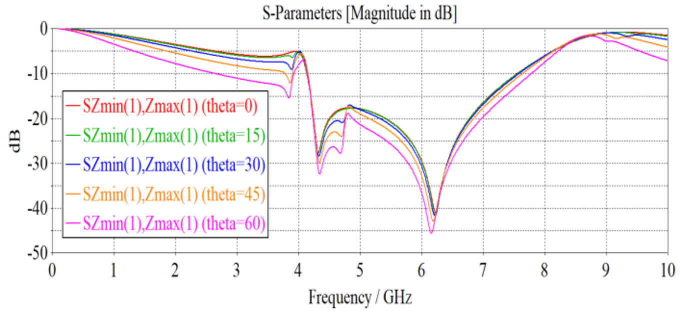


Fig. 6 Transmission coefficient at various angles of colatitude Theta (TE mode)

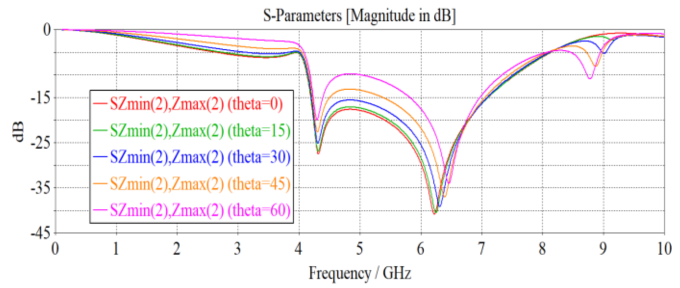


Fig. 7 Transmission coefficient at various angles of colatitude Theta (TM mode)

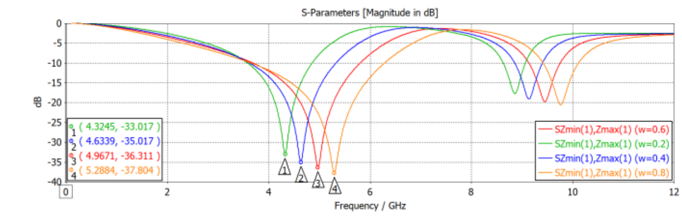


Fig. 8 Parametric study w for Fig. 1 (c)

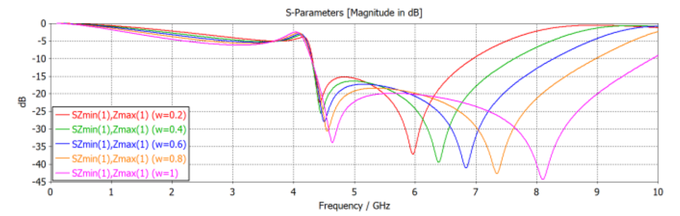


Fig. 9 Parametric study w for fig. 4

Another parametric study is performed for the broadband structure from Fig. 4. The results of varying again the width w can be seen in Fig. 9. The dimension w takes values from 0.2 to 1 in linear steps of 0.2. In this case by increasing w, the broadband shield expands from 4.4 GHz to 8.1 GHz, thus the best case obtaining a 3.7 GHz shield.

IV. Conclusions

In this paper we presented how an initial metal structure can be fractalized, thus obtaining successively one notch, two notches and afterwards a broadband shield. The initially metal cross dipole helped obtaining a notch frequency that depended inversely on its length.

The (pre)-fractalized version of the dipole provided control of the notch frequency by modifying the length of the metal pattern without affecting the dimensions of the unit cell. The combination obtained by cascading the fractalized dipole with the initial metal cross allowed for the conception of a 2-notch filter, with invariance of the transmission coefficient with respect to incident waves up to 60^{o}.

We performed a parametric study to show that the position of the notch frequencies can be controlled by geometry and we demonstrated the feasibility of a broad-band, band-stop filter that can be applied to selective screening in various applications, such as EMC tests in the Automotive industry.

Acknowledgment

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