Behaviour of Conformal Conical Frequency Selective Surfaces

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Abstract— Planar Frequency selective surfaces (FSS) have attracted large attention during the last five decades [1] because of their mechanical and electrical flexibility. FSS are spatial filters that are largely employed in applications like hybrid radomes for radars and antennas where high performance is necessary. The FSS have evolved from simple canonical forms to the complex geometries known today. This evolution has been driven primarily by increasingly stringent performance requirements of recent applications. For these structures, we must consider both the effects related to the frequency that those related to the size of the individual elements. While periodicity impacts firstly on the general reflecting properties of the surface, the shape and the size of the individual element affects its detailed both spatial and frequency filtering behaviour. In particular the frequency response is dictated mainly by the scattering of the incident plane wave by the individual element and attains its maximum at resonance conditions. Accordingly, we mean to investigate whether the same occurs also for non planar surfaces and curved elements, and in particular conical surfaces. The analysis is performed in two steps. First the frequency behaviour of input impedence of the single elements emebedded within a number of similar ones is numerically computed by a commercial code. Both single, radial and circumferential strips conforming a conical shape are considered and compared with a planar and cylindrical structure. Next the FSS behiavour is fully analysed by a numerical code solving the Electric Field Integral Equation [2] for a FSS of finite size made of thin elements.

1. INTRODUCTION

Frequency selective surfaces (FSS) have been studied for the last five decades and comprehensive books have been also published (Munk, 2000) and (Wu, 1995). FSS have evolved from simple canonical forms to the complex geometries known today. This evolution has been driven primarily by increasingly stringent performance requirements of recent applications and has been made possible by the significant improvements in the methods of analysis, from the computing capacity and on the manufacturing technology. Moreover, being FSS part of the broad family of artificial materials (Ruvio & Leone, 2014), new research efforts have been dedicated to this topic.

The FSS can be fabricated as planar two-dimensional periodic arrays of metallic elements with special geometric shapes, or may be created by periodic openings in a metal screen. The transmission and reflection properties of these surfaces are dependent on the operating frequency and may also depend on the polarization and the incidence angle of the electromagnetic wave impinging the material.

Typical frequency selective behaviour is desired in the design of hybrid radomes shielding antennas from external weather conditions. They can also lower the Radar Cross Section (RCS), outside of the frequencies of interest. If we consider, for example, an antenna mounted on the nose of an airplane, one FSS disposed on the surface of the radome allows to scatter the incident radiation that operates outside the band of interest in the bi-static direction, with the consequent result of a return very low in the direction of backscatter. A similar FSS application is in the design of band-stop filters. An example of this application is related to the realization of a hybrid radome on a shipboard radar antenna.

While the frequency behaviour of the surface is dictated both by the elements spacing and the shape of the basic element, hereafter we are interested to consider the effect of the latter one. In particular, with reference to strip elements conformed on a conical surface, the aim of this work is to examine the scattering from single element of the FSS when it is illuminated by an incident plane wave, in order to show that the frequency selective character is mainly provided by this type of contribution, and that it is not lost if the structure is not planar (at least when its radius of curvature is larger than the wavelength). Finally we show the results obtained by solving the electric field integral equation using the Method of Moments to compute the induced currents on the structure and the corresponding scattered field.

2. FREQUENCY BEHAVIOR OF STRIPS ON A CONFORMAL SURFACES

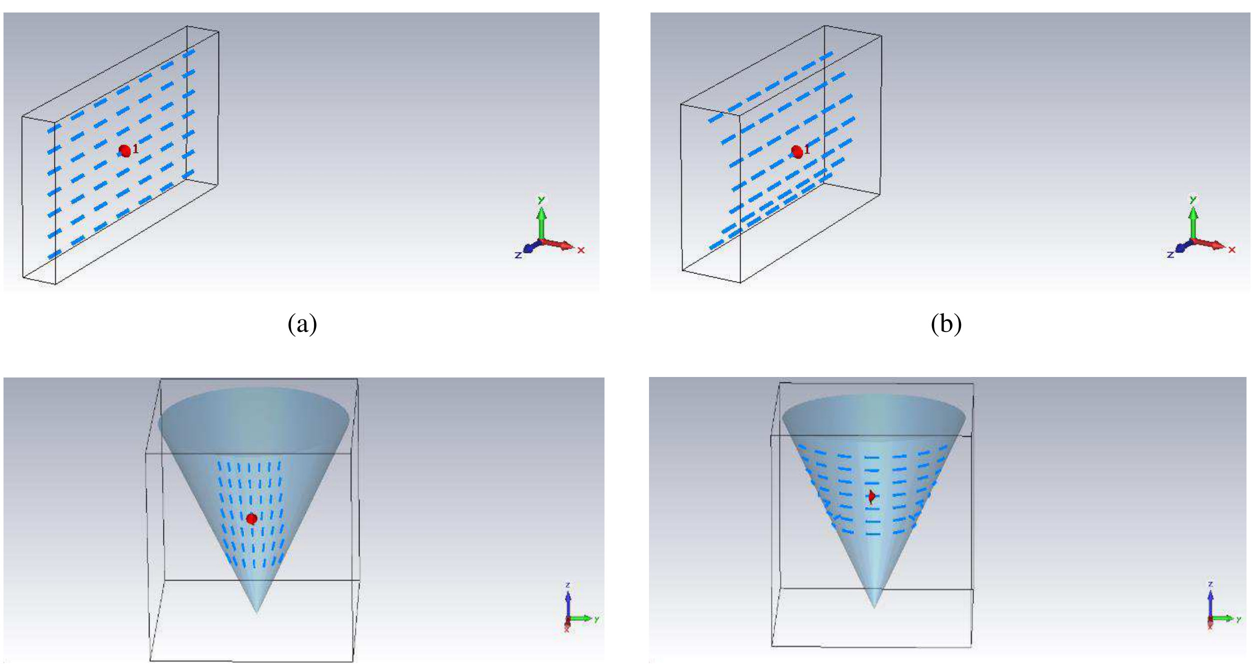
For a passive FSS the main contribution to frequency selectivity is given by the interaction of the individual element with a plane wave illuminating the structure. In fact, the electromagnetic scattering by a perfectly conducting object of a prefixed shape is dependent on its electrical dimension, and for some particular values of the frequency of the impinging wave, maximum interaction can occur. For strip or filamentary objects under short circuit conditions, the scattered field depends on both the induced current under receiving conditions and on the input impedence under transmitting conditions. In particular, the input impedence of the individual strip (in presence of all the other ones) provides the main contribution to such behavior. For an isolated straight dipole it is well known that mostly the input admittance varies with the frequency and that the modulus of the impedence is minimum at resonance condition, when the length of dipole is about half a wavelength.The same behaviour is observed when the dipole is embedded within planar arrays of similar object except for very close spacing between the elements, say, less than about a quarter of wavelength. Under resonance conditions the backscattered field is also maximum.

Much less is known when the scattering strips are not flat and/or are not arranged under a planar array, as it occurs when the FSS is not a plane. However since the main frequency filtering properties are again dictated by the scattering by the individual element (emebedded within an array of equal elements), it is worth to focus on the behaviour of its input impedence when acting as an antenna in the transmission mode.

In order to numerically compute a good approximation, we assume that only a neiboughour of a single strip can affect its input impedence, so that the problem becomes to evaluate it for a radiating strip-like dipole surrounded by a number of equal ones. Such a number is determined by examining the frequency behaviour of the input impedence with increasing number of surrounding strips and stopping when convergence is achieved.

The goal is accomplished by means of a numerical electromagnetic simulation software, providing the input impedence by varying the frequency of the incident wave on the structure. In the following, for the sake of comparison, we show the input impedence of the strips of the same type and similar configuration but arranged on a plane.

Numerical results show that the general frequency filtering behaviour is not lost for a FSS conforming a conical surface (at least for surfaces with large radius of curvatures with respect to the wavelength), since the frequency selectivity is essentially connected to the interaction of the



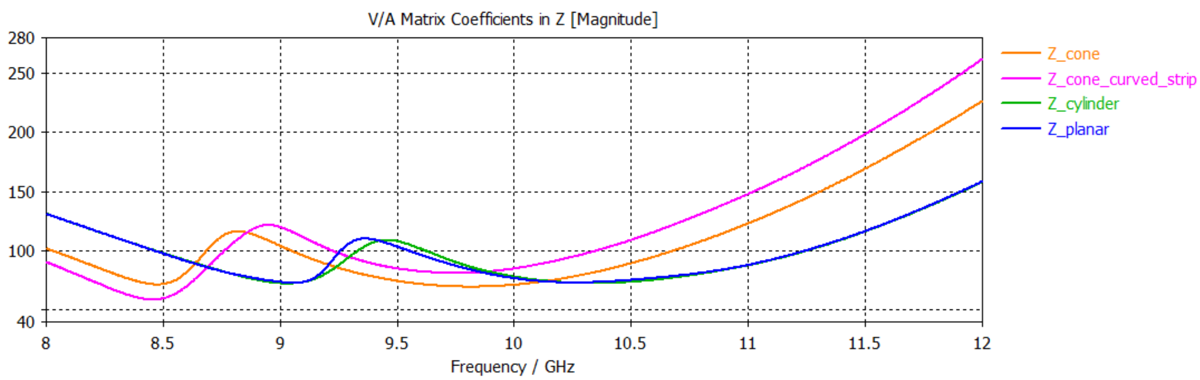
(a) (b) (c) (d)

Figure 1: The geometries of the sources: (a) planar array, (b) array conforming a cylindrical surface, (c) and (d) arrays conforming conical surfaces. The feeding points are marked by a red point.

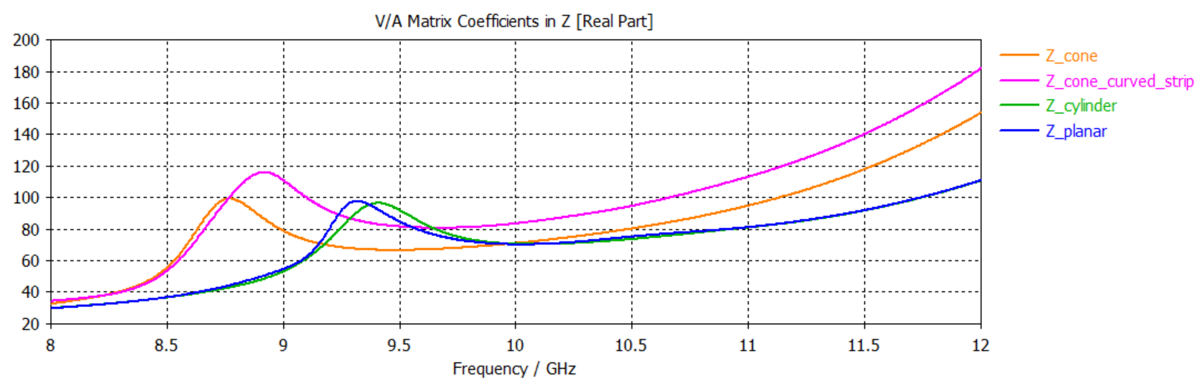
incident wave with the single element of the structure. The only apparent modification arise in the resonance frequency that can be provided by considering a limited part of the whole surface.

In order to confirm the expectations numerical experiments are performed for four finite array of two-dimensional arrays of 7×7 dipole elements, each 1.5 cm long (see Fig. 1). They are, respectively: a planar array (Fig. 1(a)), an array of rectilinear dipoles conforming a cylinder of radius 6 cm (Fig. 1(b)), an array of rectilinear dipoles radially conforming a conical surface (Fig. 1(c)), an array of curved dipoles conforming a conical surface (Fig. 1(d)). The spacing between the centers of the array elements is 3 cm along the wire direction and 1.5 cm along the orthogonal direction in all cases. The central elements are fed and the input impedence (in presence of the other passive strips) are reported in Fig. 2 within the [8–12] GHz band. The magnitude, the real and the imaginary parts of the input impedence are reported in panels (a), (b) and (c) respectively.

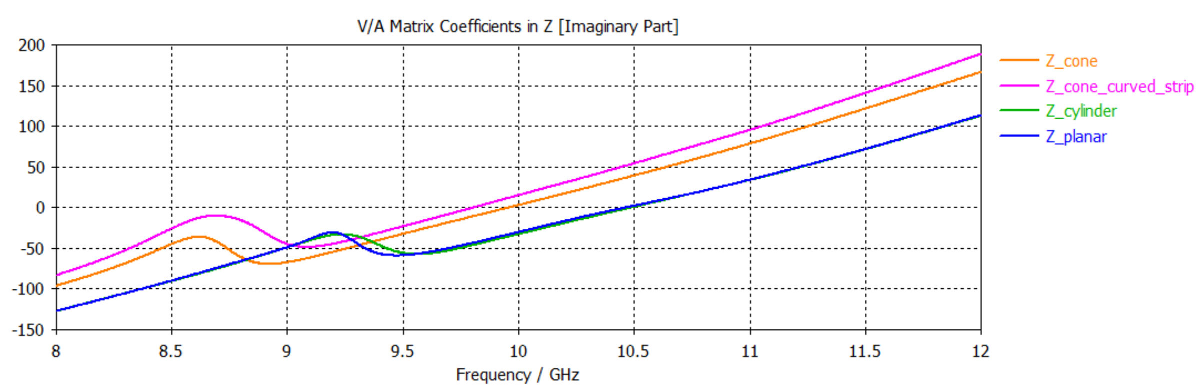
First of all, it can be observed that for planar and cylindrical cases the behaviours are very similar as both geometries are very similar. Accordingly the resonance frequency is the same, for



(a)



(b)



(c)

Figure 2: (a) Magnitude of the input impedence. (b) Real part of the input impedence. (c) Imaginary part of the input impedence.

a dipole length slightly more than $\lambda/2$. Moreover the frequency behaviour of both curves is not monotone dut to mutual coupling between the dipoles.

The same qualitative frequency behaviour holds also when dipoles are conformed on a conical surface. However the different geometrical configuration makes it possible not only to lower slightly the main resonance point but also to occur a further resonance point at a frequency lower than about 15%. This is especially true for case d) where both the dipole shape and their alignment are markedly non planar nor rectilinear.

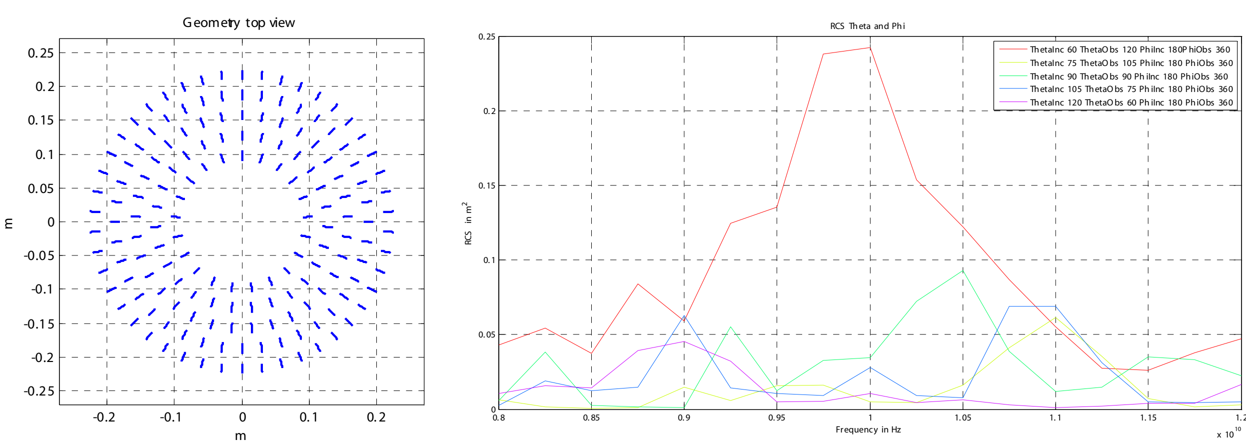
3. NUMERICAL SIMULATIONS OF 3D CONFORMAL FSS

In order to verify the above behiavour a code implementing the numerical solution of the Electric Field Integral Equation (EFIE) for strip objects has been developed. Plane wave incidence at different frequencies is considered. Thin, radially directed strips conforming to a conical surface are assumed as scatterers, so that the current induced over them can flow only radially. According to the Galerkin formulation of [2], surface density current is expanded as:

$$\mathbf{J}_s(\mathbf{r}) = \sum_{n=1}^{N} I_n \frac{f_n(r)}{r^2} \frac{1}{\Delta\varphi} \Pi\left(\frac{\varphi}{\Delta\varphi}\right) \hat{\mathbf{i}}_r$$

where the $\mathbf{f}_n$ are the 'triangle' functions as basis function $\mathbf{f}_n(r) = \Lambda(1 - \frac{|r-n\Delta r|}{\Delta r})$ and the same functions are used as test ones. After computing the impedence matrix elements and the right hand side terms, the solution of the resulting linear system allows to obtain the unknown current coefficients. The next step is to calculate the far zone field scattered by the strips, using the appropriate relations [3], and the evaluation of the Radar Cross Section, into the same range [8–12] GHz band as above, and for several incidences angle.

In the first example a finite conical FSS made of rectilinear radially directed dipole strips are considered as in Fig. 3(a), where a front view is displayed. The cone aperture is 30° and five crowns of conformal strips,each 1.5 cm long, are considered. The back scattered field for some incidence angles are reported in Fig. 3(b) within the [8–12] GHz range.



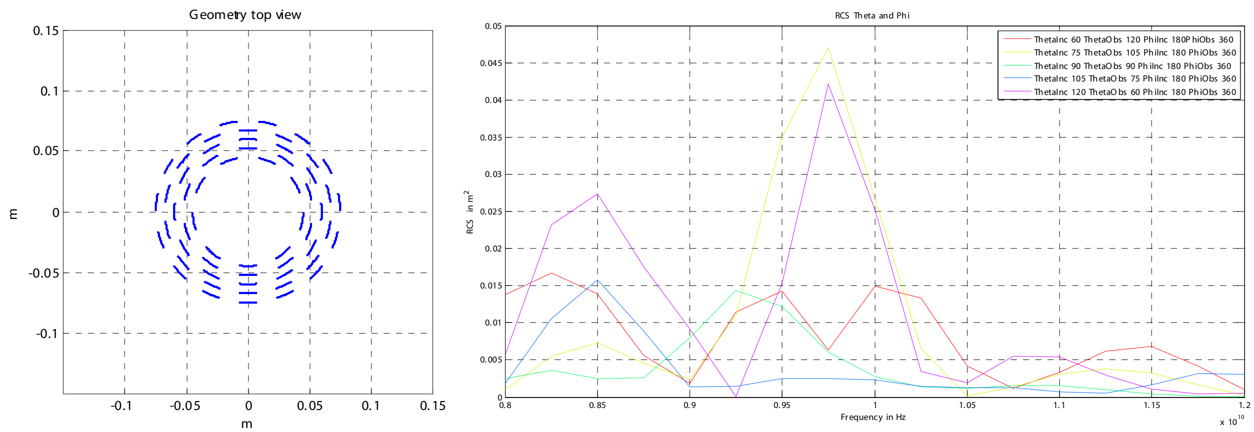
(a) (b)

Figure 3: Scattering by a conical FSS: (a) top view of the geometry; (b) magnitude of the backscattered field.

As it can be appreciated in most circumstances the backscattered filed is maximum within the same frequency range as the amplitude of input impedence, as discussed in the previous Section, is minimum.

In the second example a finite conical FSS made of curved radially directed dipole strips are considered as in Fig. 4(a), where a front view is displayed. The cone aperture is 30° and five crowns of conformal strips, each 1.5 cm long, are considered. The back scattered field for some incidence angles are reported in Fig. 3(b) within the [8–12] GHz range.

In this instance the numerical solution of the relevant EFIE is performed by expanding the



(a) (b)

Figure 4: Scattering by a conical FSS made of curved strips: (a) top view of the geometry; (b) magnitude of the backscattered field.

surface current as

$$\mathbf{J}_s(\mathbf{r}) = \sum_{n=1}^{N} I_n f_n(\varphi) \frac{1}{\Delta r} \Pi \left(\frac{r}{\Delta r} \right) \hat{\mathbf{i}}_\varphi$$

and $\mathbf{f}_n$ are again the 'triangle' functions.

Again the backscattered field is maximum within the same frequency range as the amplitude of input impedence, as discussed in the previous Section, is minimum.

4. CONCLUSION

As the frequency behaviour of a FSS is dictated mainly by the resonant interaction with the elementary scattering object, in this paper we have meant to verify whether the same occurs also for non planar surface. In particular, since the frequency behaviour of the electromagnetic scattering from a passive wire is dictated mainly by its (active) input impedence, we have numerically evaluated it for a single object (in presence of the closer ones). The backscattered field has turned to be maximum at the frequencies where the modulus of the input impedence is minimum, not only for planar FSS but also for a conical one.

ACKNOWLEDGMENT

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