EFIE BASED MULTIMODE EQUIVALENT NETWORK FOR THE ANALYSIS OF PHASED ARRAYS INTEGRATED WITH FSS

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Abstract

This contribution presents the evolution of the work on Frequency Selective Surfaces (FSS) that is being performed at TNO-FEL. In particular the extension of the previously developed Multimode Equivalent Network approach to cope with patch based structures is presented. In order to derive the network, first a set of reduced kernel integral equations that enforce the null of the tangent electric field (EFIE) on the metal surfaces are introduced. Their formal solution is then used to obtain the Z matrix that characterizes the junction in a multimode network representation. The obtained z-matrix can then be connected to the already existing software code that consents to characterize generic wave-guide geometries connected with aperture based FSS's.

Introduction

The latest trends in the applications for array antennas involve the requirement of broadband, frequency selectivity, multi-band and multi-polarization characteristics and, especially for military purposes, low Radar Cross Section (RCS). Some of these requirements can be fulfilled integrating directly in the antenna design polarizing grids, dielectric radomes and in general frequency selective surfaces (FSS). However at the present state of the art these latter are usually designed as stand alone elements and then fitted with the array antenna in a second phase. In this conditions the full control of the performances of the overall structure is not a straightforward matter.

In order to tackle these geometries, the Antenna group in TNO has recently developed a dedicated tool. This latter [1][2] allows one to easily analyze structures that involve tuning elements as well as filtering structures inside the waveguides of a conformal or planar phased array. Moreover it consents to analyze frequency selective screens and radomes in front of the array.

The code is based on the Multi-mode Equivalent Network formulation (MEN) which obtains the multi-mode impedance matrix of the whole periodic cell as a cascade of multi-mode impedance matrices. These matrices can be associated to each waveguide and to the transitions between two adjacent waveguides. It should be noted that these waveguides could also be phase shift waveguides (dielectric radomes).

The basic idea that renders extremely efficient this network representation consists in separating the modes excited at each discontinuity in accessible and localized modes. The accessible modes are lower order modes responsible for the energy exchange while the localized modes are higher order modes, which contribute to the stored energy. Therefore the fundamental plus a few higher order modes are the accessible ones, while the localized modes are all the remaining non-propagating modes. On this basis, each line can be represented by an impedance matrix with as many input and output terminals as the number of accessible modes that propagates in the line (multi-mode impedance matrix). The multi-mode impedance matrix of the transition between two lines is then calculated by solving the Integral Equation that characterizes the fields and the currents at the transition. A Frequency Extraction technique is used in order to accelerate the numerical solution of the Integral Equation. Such a formulation has already been successfully applied to the analysis of multi-layer conformal or planar structures containing slot FSS (thick slotted metal screens)[4].

In this paper the formulation is extended to the study of structures, containing patch based FSS. At difference with previous MEN formulations for FSS structures that used a set of Integral Equations (IE) representing the Continuity of the Magnetic field, the present paper uses a set of electric field based integral equations.

Formulation

Let us consider a Frequency Selective Structure that is composed of a generic periodic array of conductors *(P)* lying in the x,y (z=0) plane, that separates region 1(ϵ_{r1}) and region 2(ϵ_{r2}). The geometry is shown in Fig. 1. Since both the excitation and the structures are assumed to be periodic the electric field at z=0, tangent to the array plane, can be expanded in terms of Floquet's Modes, that we will indicated as $\boldsymbol{e}_t^i(\boldsymbol{r})$. (Note that the Floquet's modes on both sides of the array (z>0 or z<0) are the same independently of the dielectric and that $\boldsymbol{r}=(x,y)$). The starting equation imposes the vanishing condition of the total tangent electric field on the patch surface, i.e.:

$$\sum_{i=1}^{\infty} V_i^{(2)} \boldsymbol{e}^i(\boldsymbol{r}) = 0 \qquad \forall \boldsymbol{r} \in P \tag{1}$$

The modes that compose the total field are separated in accessible and non accessible modes. In general, for certain FSS multi layered geometry, the non accessible modes in a Floquet's expansions are all the modes that do not contribute to the interaction between the considered FSS and the two adjacent layers. So, the non accessible modes can be individuated a priori, before the actual start of the analysis, based on the cut off frequency of the modes themselves. Equation (1) then becomes

$$\boldsymbol{E}_t(\boldsymbol{r}) = \sum_{i=1}^{N_a} V_i \boldsymbol{e}^i(\boldsymbol{r}) + \sum_{i=N+1}^{\infty} V_i \boldsymbol{e}^i(\boldsymbol{r}) = 0 \tag{2}$$

where N_a is the number of accessible modes to be considered and V_i are the corresponding weights of the electric field modes. It is also convenient to synthetically express the accessible and non accessible fields as: $\boldsymbol{E}_t = \boldsymbol{E}_a + \boldsymbol{E}_{na}$. so that I.E. (2) becomes

$$\sum_{i=1}^{N_a} V_i \boldsymbol{e}^i(\boldsymbol{r}) = -\boldsymbol{E}_{na}. \tag{3}$$

Let us represent the equivalent electric current on the patch P as

$$\boldsymbol{J} = \sum_{i=1}^{N_a} V_i \boldsymbol{J}_d^i(\boldsymbol{r}) \tag{4}$$

where $\boldsymbol{J}_d^i$ are vectorial unknowns. Eq. (4) states that, given the weights of the electric field modal function, the actual equivalent electric currents can be expressed as superposition of certain unknown $\boldsymbol{J}_d^i$. Let us also note that the Infinite Array Green's function for this kind of problems can also be expressed as superposition of Floquet modes $\boldsymbol{G}(\boldsymbol{r},\boldsymbol{r}') = \sum_{i=1}^{\infty} Z_i \left(\boldsymbol{e}^i(\boldsymbol{r}) \boldsymbol{e}^{i*}(\boldsymbol{r}')\right)$, where Z_i is the characteristic impedance of the i-th Floquet mode. Introduced the notation $\boldsymbol{G}(\boldsymbol{r};\boldsymbol{r}') = \sum_{i=1}^{\infty} \boldsymbol{G}_i(\boldsymbol{r};\boldsymbol{r}')$, it is consequently possible to define the non accessible portion of the Green's function as

$$\boldsymbol{G}_{na}(\boldsymbol{r};\boldsymbol{r}') = \boldsymbol{G}(\boldsymbol{r};\boldsymbol{r}') - \sum_{i=1}^{N_a} \boldsymbol{G}_i(\boldsymbol{r};\boldsymbol{r}') \tag{5}$$

This definition consents then to express the non accessible electric field in terms of the total equivalent currents as:

$$\int_{P.} \boldsymbol{G}_{na}(\boldsymbol{r};\boldsymbol{r}') \cdot \boldsymbol{J}(\boldsymbol{r}') d\boldsymbol{r}' = \boldsymbol{E}_{na} \tag{6}$$

By using (4) and (5) in (3) and equating similar addend terms, one obtains the set of reduced integral equations

$$\boldsymbol{e}^i(\boldsymbol{r}) = -\int_P \boldsymbol{G}^{na}(\boldsymbol{r};\boldsymbol{r}') \cdot \boldsymbol{J}_d^i(\boldsymbol{r}') \qquad (7)$$

We have thus obtained an integral equation for each one of the accessible modes. The *kernel* of this I.E. is constituted by the non accessible Green's function while the unknowns $\boldsymbol{J}_d^i$ which are obtained for each different forcing term are the currents associated by this kernel to the patch.

Equivalent Network

From this set of integral equation the derivation of the pertinent modal network follows as in [3]. Tthe network must provide the constitutive relations between $\boldsymbol{V}$ and $\boldsymbol{I}=(\boldsymbol{I}_1-\boldsymbol{I}_2)$, where the pedix 1 and 2 refer to the regions for $z<0$ and $z>0$ respectively. Therefore it is connected in parallel to the remaining network composing the overall system as in Fig. 2. V_i and I_i refer to weights of the Floquet's electric and magnetic modes at the interface and thus related via the representation of the total magnetic field at the interface.

$$\sum_{i=1}^{\infty}(I_1^i \boldsymbol{h}_1^i - I_2^i \boldsymbol{h}_2^i) = -\boldsymbol{n} \times \sum_{j=1}^{N_a} Vj \boldsymbol{J}_d^j \qquad (8)$$

Since $\boldsymbol{h}_1^i(z=0)=\boldsymbol{h}_2^i(z=0)$, multiplying multiplying left and right term by $\boldsymbol{h}^{j*}$ and integrating over the patch surface (8) becomes

$$\sum_{i=1}^{\infty}(I_1^i - I_2^i))\int_P \boldsymbol{h}^i \cdot \boldsymbol{h}^{j*} = -\boldsymbol{n} \times \sum_{j=1}^{N_a} V_j \int_P \boldsymbol{J}_d^j \cdot \boldsymbol{h}^{j*} \qquad (9)$$

which, using the orthogonal relationship of the Floquet modes and simple algebraic manipulations gives:

$$(I_1^i - I_2^i)) = \sum_{j=1}^{N} V_j \; Y_{ij} \qquad \text{where} \qquad Y_{ij} = \int_P \boldsymbol{J}_d^j \cdot \boldsymbol{e}^*_{\boldsymbol{i}} \qquad (10)$$

Conclusions

A code has been developed to derive the MEN representation of a generic patch based FSS. The code uses Piece Wise sinusoidal small domain basis function to solve the reduced kernel integral equations in (7). The code has recently been tested on test cases already present in literature showing conforting results. As an example here we report, fig.3, the reflection coefficient for a free standing dipole FSS under normal plane wave incidence (the details are in the caption). The MoM solution utilizes 21 basis functions and the agreement with the results obtained by [5] is very good. This portion of the code has been connected to the already available code that deals with generic waveguide transitions, waveguide arrays and aperture based FSS, so that an integrated design can now be achieved. In order to validate the code and show the potentials of such approach the bread boarding of a FSS is presently also being conducted. The essential design enhancement is then obtained which consists in accounting for the interaction between closely mounted different compoents within a unified approach.

References

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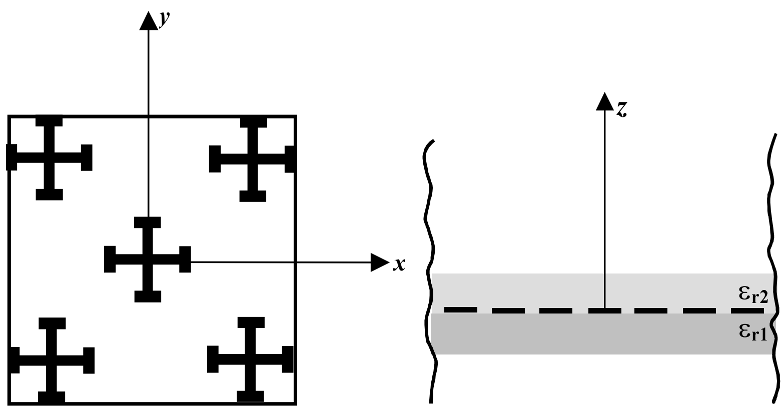

Figure 1. *Generic patch based layered FSS and relevant reference system.*

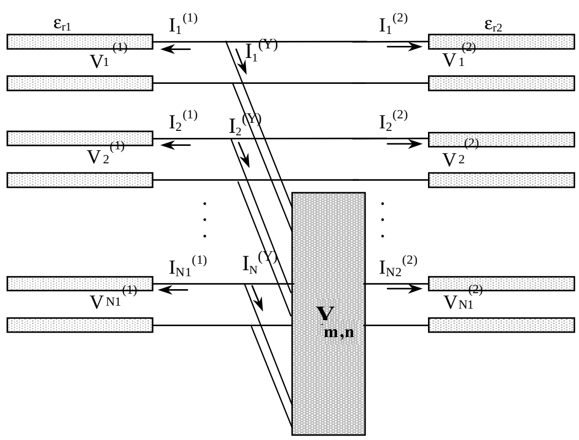

Fig. 2 *Parallel network equivalent to the patch based FSS and it's connection to the overall cascade network*

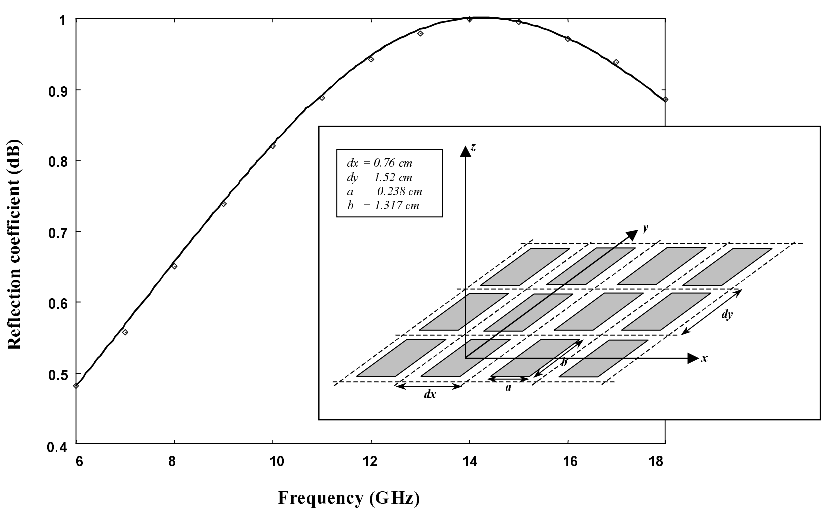

Fig. 3 *case study of a free standing array of dipoles (MEN solid line,[4] dots)*