MULTI-LAYER INTEGRATED FREQUENCY SELECTIVE SURFACES

FOR PLANAR AND CONFORMAL CYLINDRICAL PHASED ARRAYS

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ABSTRACT

In this contribution, we present an efficient approach for the design of multi-layer planar and cylindrical arrays with integrated Frequency Selective Surfaces (FSS's). The design of such arrays responds to the more and more demanding requirements on modern array antennas in terms of structural integration and reduced Radar Cross Section (RCS). The proposed approach is based on an Integral Equation Multi-mode Equivalent Network formulation and the Unit Cell approach. The value of the results presented is in that, due to the modularity of this formulation, dielectric radomes and frequency selective screens in front of the array, as well as additional junctions and waveguide discontinuities, can be easily included in the analysis.

INTRODUCTION

A variety of military systems employ multiple antenna apertures on a single platform such as a ship or an aircraft. In order to reduce cost and improve performance characteristics such as RCS, it is desirable to combine multiple functions into a single aperture. Wide bandwidth, multi-polarization phased arrays with frequency selectivity properties are needed to accomplish this goal.
Also the new trends in the communication market are demanding for low cost, lightweight array antennas with wider bandwidths and consequently higher frequencies and higher bit rates.

Another key issue of modern array systems is the use of integrated antennas, where this definition can be considered in a very wide sense:

- **Structural integration**. The antenna has to fit on a platform whose dimensions and shape are dictated by aerodynamic and/or structural and/or space constraints. In addition to the evident *structural* benefits, the adoption of conformal antennas, which can fit on arbitrary shaped platforms, provides also a number of *operational* benefits. For example: elimination of moving parts, potential increase of the available aperture (providing narrower beam-width and possibly higher antenna gain), wider scan angles and reduced RCS (the antenna could follow low-RCS shapes).

- **Multi-layer radiating structures**. A new paradigm for designing modern multifunction structurally integrated array radars for low RCS platforms is the use of multi-layer structures with integrated radomes and Frequency Selective Surfaces (FSS's).

Furthermore, the traditional hardware development, based on the manufacture and measurement of test components, is too expensive and time consuming. Therefore, the availability of novel integrated design tools and manufacturing techniques has become an essential requirement.

Waveguide radiators may not always appear as the most obvious choice for lightweight, wide-band arrays, as microstrip patch antennas. Nevertheless, in recent years, technology has matured to the point where the realisation of very compact and light conformal arrays, using open-ended waveguide radiators integrated with T/R modules, has become realistic and cost-effective. In addition, waveguide radiators are known for their inherent wide band characteristics, and they have the unique feature of high-pass filtering behaviour, due to the cut-off frequencies of the waveguide modes. Furthermore, they have very well predictable characteristics, good element impedance matching over a large bandwidth and within a wide scan angle, and it is still possible to have small dimensions employing a proper dielectric filling. Recently, dielectric loaded waveguide radiators have been proposed to achieve high-density microwave packaging [1].

MULTI-MODE EQUIVALENT NETWORK (MEN) FORMULATION

In this contribution, we present an accurate and efficient tool for the analysis of multi-layer planar and conformal cylindrical arrays of open-ended waveguide radiators, based on a Multi-mode Equivalent Network (MEN) formulation [2], [3] and the Unit Cell approach [4].

The modularity of the MEN formulation allows a very efficient analysis of multi-layer complex structures where dielectric radomes and frequency selective screens in front of the array, as well as additional junctions and waveguide discontinuities (tuning or filtering elements) can be easily included in the analysis. In the first formulation [3], the FSS's were analyzed as thick slotted metal screens. The formulation has now been extended to the dual problem, therefore allowing the analysis of patch based FSS's [5].

The basic idea of the proposed approach is the decomposition of the structure into the cascade of waveguide sections coupled through a common surface. Once the modal spectrum of each region is known, for each coupling junction a multi-mode equivalent network is derived by means of an efficient integral equation formulation. The complete structure, then, can be analyzed by simply cascading the multi-mode equivalent networks of lines and junctions alternatively.

One interesting aspect of the proposed technique is in the fact that its modular approach allows an efficient design process. In fact, only those parts of the complete structure which have been actually modified need to be characterized again, keeping unchanged the multi-mode network representation of the rest of the structure.

Another key feature of this formulation is the adoption of the "accessible" and "localized" modes concept. The accessible modes are the first modes excited by the discontinuity that "see" the successive discontinuity (all the propagating modes plus first few non-propagating modes). The localized modes are all the infinite remaining modes that remain localized in the neighborhood of the discontinuity. The multi-mode equivalent network presents as many input and output ports as the number of accessible modes, but does not neglect the higher order modes that are kept in the kernel of the integral equation.

In conclusion, this tool gives the opportunity to design complex integrated array structures considering the array antenna as a whole. This allows taking full advantage of the integration of the array antenna with the FSS's and gives to the designer a number of different options and different degrees of freedom in the design process. In particular, it is offered the possibility to combine waveguide and dichroic filtering.

RESULTS

A first validation of the tool has been done comparing the theoretical simulations of an open-ended waveguide planar array with results available in literature [6]. Numerical results for the reflection coefficients at the input waveguide are shown in Fig.2. These results are presented for different scan angles, and different wall thickness in the plane of scan. This last parameter is defined as $t_p=(b-a)/b$, in agreement with the definition adopted in [6].

For the cylindrical case, a comparison with experimental results (Fig.3) has been done measuring the reflection coefficient and the inter-element coupling of an X-band circular cylindrical demonstrator.

The next important step in the development of the tool has been the integration of FSS's and dielectric radomes with the array. No experimental data are available in the open literature for this kind of multi-layer structures. An X-band demonstrator of a planar array consisting of open-ended square waveguides, loaded with a configuration of single or double FSS panels, is under development. Experimental results will be available at the conference.

In Fig.4, the reflection coefficient of a planar array, loaded with two identical FSS's (aperture based), vs. frequency is shown for different lengths of the first "cavity", delimited by the array plane and the first FSS. The effect of this length on the filtering behavior of the structure is mainly a shifting of the resonance frequency, as can be observed from the curves of Fig.4. The "cavity" length is one of the different design parameters which include also the "coupling apertures" (rectangular irises at the waveguide-free-space interfaces and apertures of the FSS) and the dielectric permettivity of the dielectric layers.

In Fig.5, we report the design of planar and cylindrical multi-layer arrays including two FSS's. In particular, two cylindrical cases are compared with an equivalent planar array. The two conformal cases correspond to two different numbers (N=100 and N=200) of radiating elements distributed all the way around the cylinder. In order to keep fixed the inter-element distance, the radius of the cylinder has been chosen accordingly. The scope of Fig.5 is to show the effect of the gradual cut-off of the radial modes supported by the cylindrical structure. In this case, in fact, the Phase-Shift Wall Waveguide, describing the free space under the periodic conditions dictated by the array, has a radial configuration. The wave impedance of the modes supported by these structures is a function of the radial coordinate, and for the same frequency can show a predominantly resistive or reactive behavior depending on the radial position. The transition point is called gradual cutoff point [7].

This effect is confirmed by the curves of Fig.5 for the cylindrical case. In fact, although the same inter-element distance has been chosen for the two cases, the different radius of curvature has the effect of changing the propagation properties of the higher order modes (S13 curves: coupling between the fundamental rectangular mode and the first higher Floquet's mode) with a corresponding degradation of the filtering behavior. This problem does not affect the planar structure where the unit cell dimensions are fixed and all the higher order modes are below cutoff.

CONCLUSIONS

In this contribution, we have presented an efficient approach for the design of planar and cylindrical arrays with integrated Frequency Selective Surfaces (FSS's). The FSS's, modeled as thick slotted metal screens, are interleaved with dielectric layers and directly integrated with the array, forming a multi-layer structure. The filtering behavior of this structure can be designed by properly choosing few geometrical parameters. The modularity of the approach allows also the design of structures where tuning and filtering elements are placed into the feeding waveguides. A further development of this tool is represented by the characterization of patch based FSS's. The formulation of this problem has been completed and will be presented at this conference.

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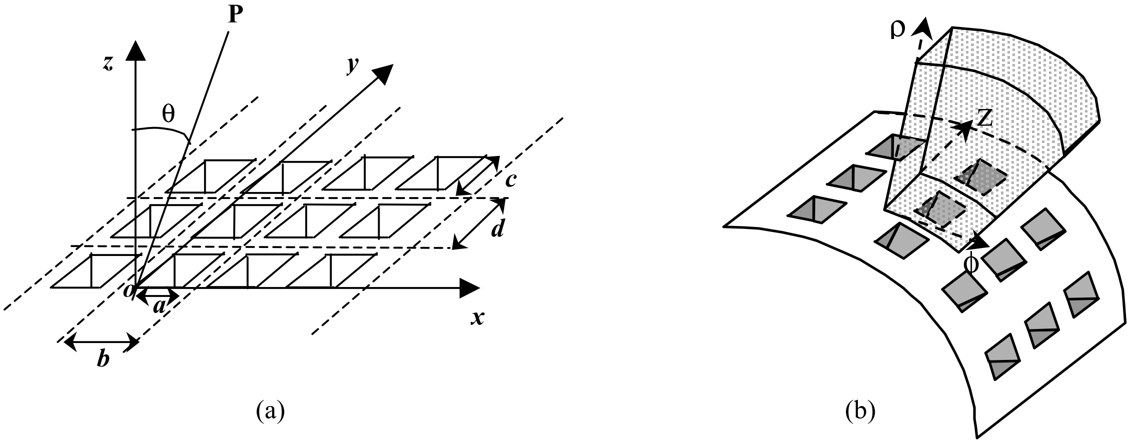

(a) (b)

Fig. 1 : Planar (a) and cylindrical (b) arrays of open-ended waveguides. Reference systems.

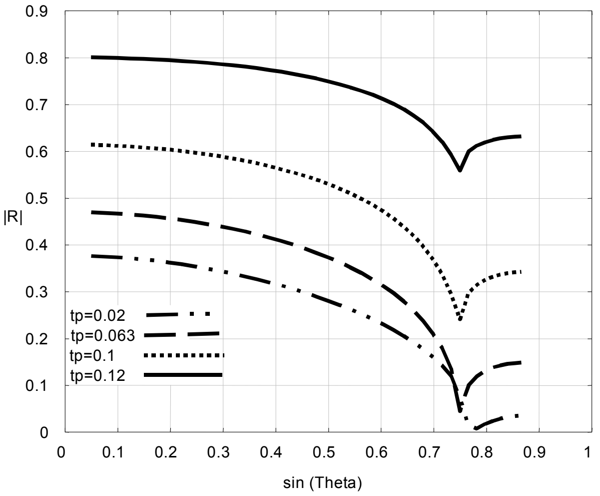

Fig. 2 : Reflection coefficient at the input waveguide of a planar array vs. scan angle, for different wall thickness (t_p) (See [6] for comparisons).

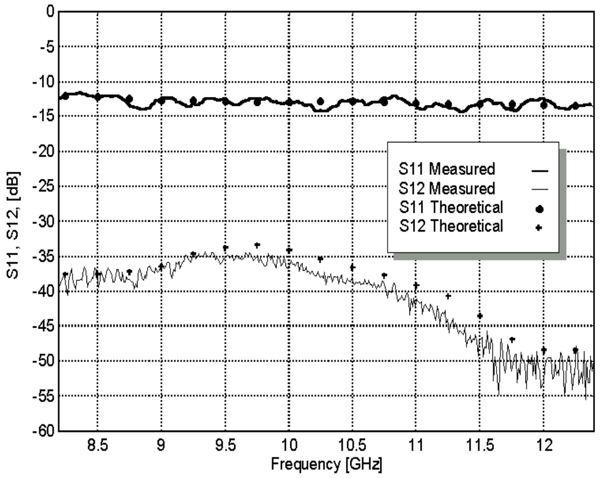

Fig. 3 : Theoretical and experimental results for an X-band cylindrical array of open ended waveguides. S11 is the reflection coefficient at the input waveguide. S21 is the coupling coefficient between two adjacent elements on the same column.

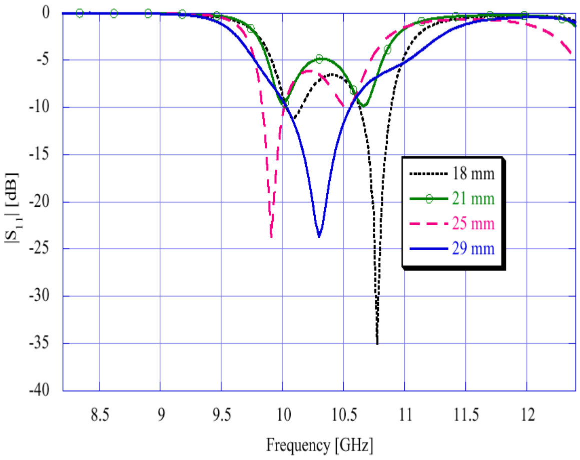

Fig. 4 : Reflection coefficient of a planar array, loaded with two identical FSS's, vs. frequency, for different lengths of the first "cavity" (distance between the plane of the array and the first FSS).

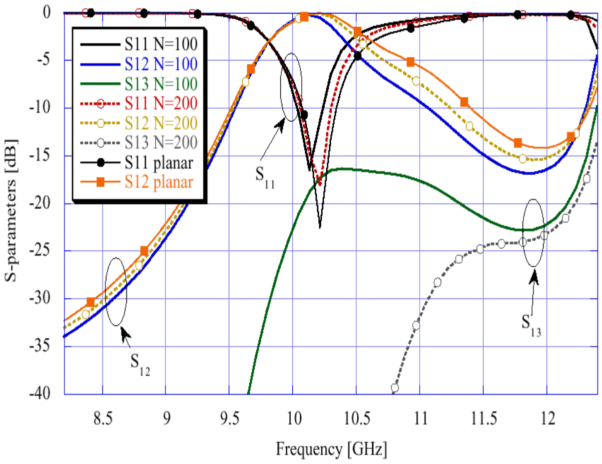

Fig. 5 : S-Parameters of planar and cylindrical arrays loaded with two FSS's.