EFFICIENT ANALYSIS OF DICHROIC PLATES FOR LARGE REFLECTOR ANTENNAS

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ABSTRACT

This paper presents a novel method for the analysis of dichroic plates, used for combining signals at different frequencies in the beam–waveguide feeding system of large reflector antennas for deep–space applications. This method applies to the analysis of either single or multiple metal screens perforated periodically with holes. The holes perforating the metal screen may have an arbitrary cross–sections and, possibly, include steps. This method, named the MoM/BI–RME method, is based on the solution of an integral equation by the Method of Moments (MoM) using entire–domain basis functions, efficiently obtained numerically by the Boundary Integral–Resonant Mode Expansion (BI–RME) method. The MoM/BI–RME method was used for the analysis and design of many dichroic plates for radio–astronomy. Some of these examples are reported in the paper.

INTRODUCTION

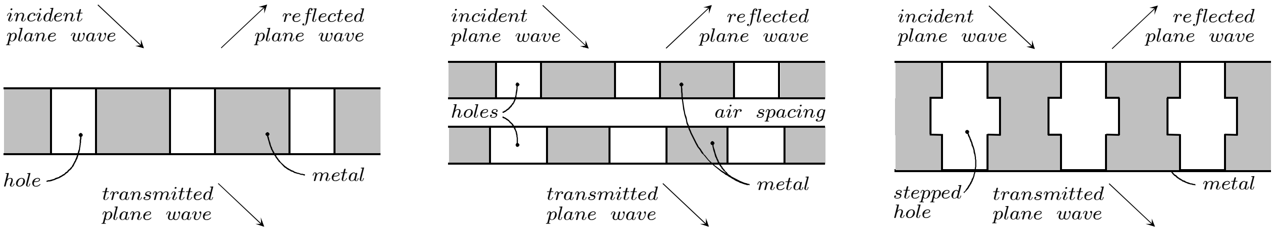
Large reflector antennas for radio–astronomy applications usually operate in more than one frequency band (typically the S, X, and Ka bands). The feeding system of such antennas frequently consists of a beam waveguide, where the combination of signals at different frequencies can be performed by dichroic plates [1].

In the basic configuration, dichroic plates (also called *FSSs*, Frequency Selective Surfaces) consist of a thick metal screen perforated periodically with apertures (Fig. 1*a*) [2]. The geometry of the apertures and the thickness of the metal screen determine the frequency bands where the dichroic plate is transparent and the ones where it is a perfect mirror. More complicated configurations are sometimes used, in order to achieve better performance: multi–grid structures (Fig. 1*b*) and metal plates perforated periodically with stepped–holes (Fig. 1*c*) have been proposed [3].

Recently, we developed an efficient method for the analysis of dichroic plates [4]. This method, named the MoM/BI–RME method, is based on the infinite array approximation and permits the analysis of dichroic plates with arbitrarily shaped apertures. The peculiarity of this method consists in the use of the Boundary Integral–Resonant Mode Expansion (BI–RME) method for the numerical calculation of entire–domain basis functions, needed in the analysis by the Method of Moments (MoM).

The MoM/BI–RME method was implemented in fast and flexible computed codes. One of them applies to the analysis of single–grid dichroic plates, perforated with arbitrary apertures and illuminated by a uniform plane wave incident at an arbitrary angle [4]. This code permits the wideband analysis of dichroic plates in few seconds on a standard PC. This code was used for the design of a S–/X–band dichroic mirror to be operated in the deep space antenna of the European Space Agency (ESA) in Perth, Australia [2]. This antenna is required for future deep space missions by ESA, such as Rosetta and Mars Express. Another code was implemented for the analysis of multi–grid dichroic plates [5]. By using the segmentation technique and the infinite array approximation, the structure reduces to a number of step discontinuities between a metallic waveguide and a waveguide with periodic boundary conditions, where the field is expressed as a combination of Floquet modes. Each discontinuity is analyzed by the MoM/BI–RME method. Finally, a code was implemented for the analysis of metal plates perforated with stepped holes [6]. In this case, the structure reduces to the cascade of two types of discontinuities: the discontinuity between two metallic waveguides with different cross–sections and the one between a metallic waveguide and a waveguide with periodic boundary conditions.

The basic theory of the MoM/BI–RME method is presented in this paper, along with its application to the analysis of single– and multi–grid dichroic plates, and metal plates perforated with stepped apertures. Some application examples are also addressed, both in the microwave and in the mm–wave range.



(*a*) (*b*) (*c*)

Fig. 1 – Configurations of dichroic plates: (*a*) single–grid; (*b*) double–grid; (*c*) plate perforated with stepped holes

MOM/BI–RME METHOD

Under the infinite array approximation, the analysis of single–grid FSSs is based on the formulation of an integral equation (IE) for the unit cell. The IE is obtained by imposing the continuity of the tangential component on the fields across the discontinuity and is solved by using the MoM. The unknowns of the IE (*i.e.*, the magnetic current densities on the terminal cross–sections of the hole) are expanded on a set of entire–domain basis functions, which are the modal vectors of a waveguide with the same cross–section of the hole. Such a waveguide may have an arbitrary cross–section, and its modes are calculated numerically by the BI–RME method in a very fast and accurate way [4]. Moreover, the coupling integrals between waveguide modes and Floquet modes, appearing in the MoM matrices, are transformed from surface to line integrals [7], and are obtained practically as a by–product of the BI–RME calculation of the modes.

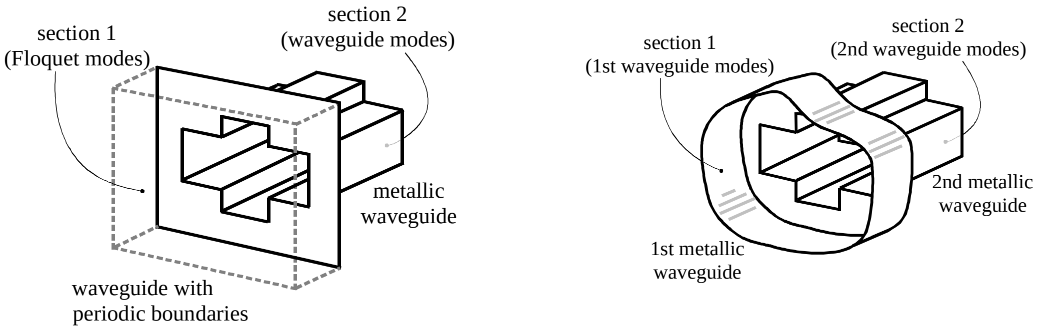
The same approach can be extended to multi–grid and stepped–hole FSSs. However, in this case, it is convenient to use the segmentation technique and divide the unit cell into a number of elementary building–blocks. Each block can be analyzed separately and characterized through its Generalized Admittance Matrix (GAM). Finally, the GAMs of the building–blocks are recombined, in order to determine the admittance matrix of the whole component and, therefore, its transmission and reflection properties. In particular, in the case of multi–grid FSSs, the structure reduces to a number of step discontinuities between a waveguide with periodic boundary condition (the Floquet unit cell) and a metallic waveguide with a cross–section coincident with the hole shape (Fig. 2*a*). Conversely, in the case of FSSs perforated with stepped holes, the structure reduces to both step discontinuities between a waveguide with periodic boundary condition and a metallic waveguide, and step discontinuities between two metallic waveguides with different cross–sections (Fig. 2*b*). The GAM is obtained by solving an integral equation problem by the MoM method [6]. Also in this case, the MoM matrices requires the calculation of the modes of the metallic waveguide(s) and of the coupling integrals between the two sets of modes at the interface (*i.e.*, between the waveguide modes and the Floquet modes in the case of Fig. 2*a*, and between the modes of the first and second metallic waveguide in the case of Fig. 2*b*).

NUMERICAL AND EXPERIMENTAL RESULTS

The first example refers to a S–/X–band dichroic plate, designed for the deep–space antennas of European Space Agency (ESA), which will support the Rosetta Mission [2]. The mirror is a plate perforated with cross–shaped holes (Fig. 3*a*), and was machined by milling technique. Thanks to the flexibility of the MoM/BI–RME method, the rounded corners in the cross–section of the holes, due to the fabrication process (Fig. 3*b*), were considered in the design, and this permitted to obtain the excellent agreement between simulation and measurement, as shown in Figs. 3*c* and 3*d*.

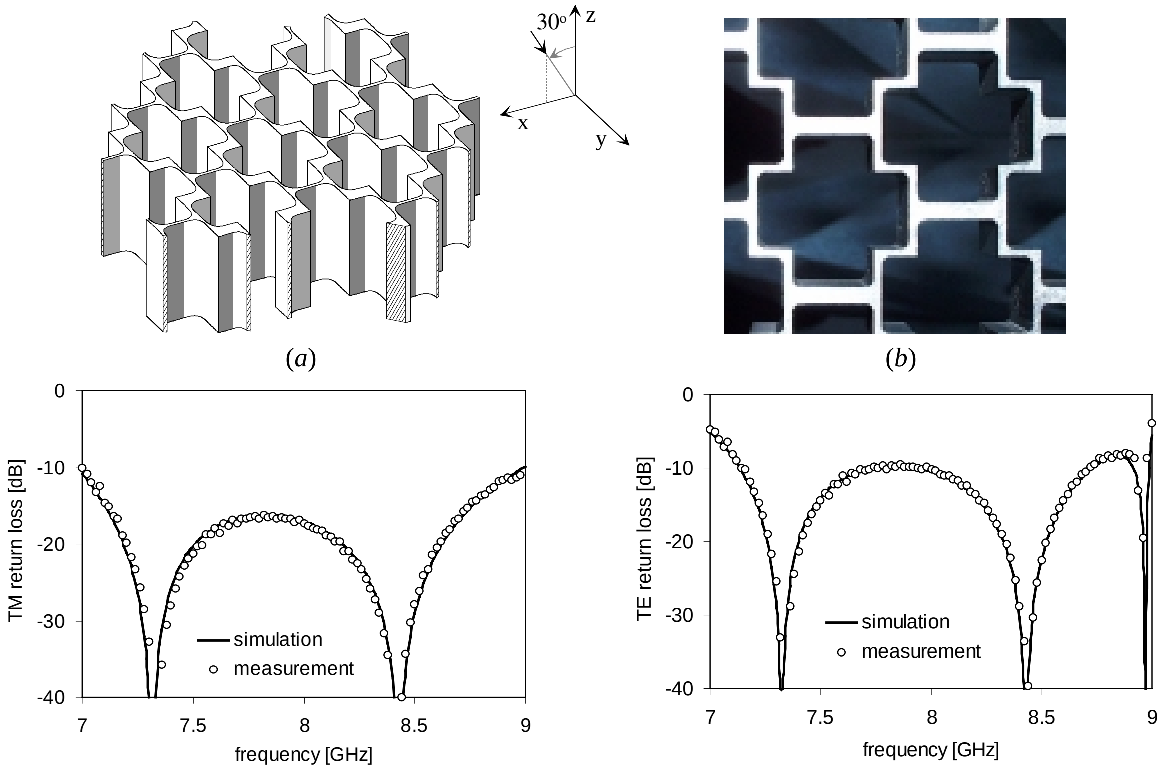
The second example refers to the waveguide simulator of a two–grid FSS with rectangular apertures reported in Fig. 4*a*. After segmenting the structure into four identical discontinuities (Fig. 4*b*) of the type of Fig. 2*a*, we considered 8 accessible and 270 localized Floquet modes, and 12 waveguide modes. The overall CPU time for the calculation of the frequency response in 200 frequency points was 18 *sec* on a Pentium III @ 1 *GHz*. The simulated and measured reflection and transmission coefficients, both in magnitude and in phase, are reported in Figs. 4*c* and 4*d*.

The third example refers to a dichroic mirror, consisting of a thick screen perforated with stepped rectangular apertures [3] (Fig. 5*a*). This structure was segmented into six discontinuities (Fig. 5*b*) of both types (Figs. 2*a* and 2*b*). We considered 2 accessible and 300 localized Floquet modes, and 4 accessible and 90 localized waveguide modes. The overall CPU time for calculating the frequency response in 100 frequency points was 25 *sec* on a Pentium III @ 1 *GHz*. The reflection and transmission coefficients of the TE and TM modes are reported in Figs. 5*c* and 5*d*, respectively, and compared with measurements.



(*a*) (*b*)

Fig. 2 – Waveguide step discontinuities: (*a*) discontinuity between a waveguide with periodic boundaries and a hollow metallic waveguide; (*b*) discontinuity between two hollow metallic waveguides.



(*a*) (*b*)

(*c*) (*d*)

Fig. 3 – S–/X–band dichroic plate with cross–shaped apertures: (*a*) schematic of the dichroic plate; (*b*) photo of some elements, showing the rounded corners due to the fabrication process; (*c*) simulation and measurement of the TM reflection coefficient; (*d*) simulation and measurement of the TE reflection coefficient.

CONCLUSION

In this paper, we presented a novel and flexible method for the analysis of single– and multiple–screen dichroic filters. This method, named the MoM/BI–RME method, applies to the analysis of metal plated perforated with arbitrarily shaped, possibly stepped, holes. Some examples demonstrated the capabilities of the method, as well as its rapidity and accuracy.

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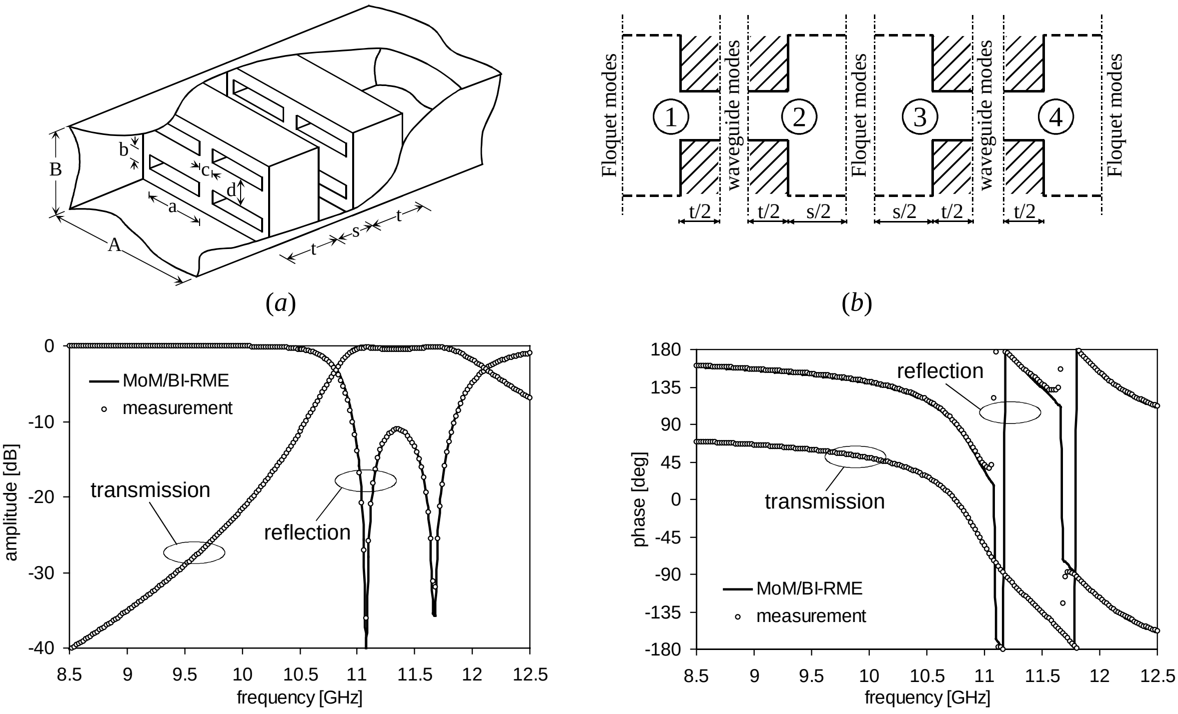
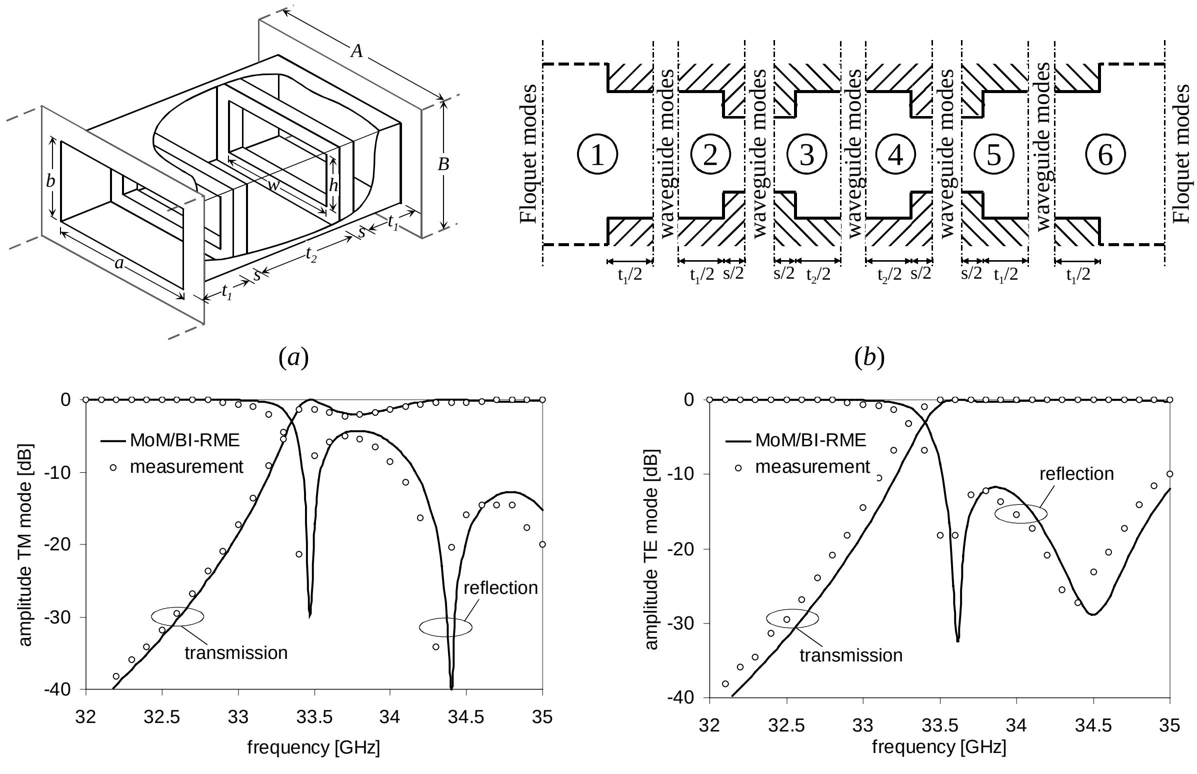


(*a*) (*b*)

(*c*) (*d*)

Fig. 4 – Waveguide simulator of a two–screen FSS: (*a*) schematic of the structure (dimensions in *mm*: A=31.5, B=12.6, a=14.1, b=2.0, c=1.65, d=4.3, t=10, s=7); (*b*) segmentation used in the analysis; (*c*) simulated and measured amplitude of the transmission and reflection coefficients; (*b*) phase of the transmission and reflection coefficients.



(*a*) (*b*)

(*c*) (*d*)

Fig. 5 – Dichroic filter with stepped apertures: (*a*) schematic of the unit cell (dimensions in *mm*: *A*=5.6388, *B*=4.8833, *a*=4.62, *b*=4.6116, *w*=3.8331, *h*=3.9406, t_1=9.8044, t_2=9.144, *s*=0.508; incidence angle: θ=30°, ϕ=0°); (*c*) simulated and measured TM transmission and reflection; (*d*) simulated and measured TE transmission and reflection.