Analysis of a Finite Array of Open-Ended Waveguides Based on a Multimode Equivalent Network Including the Effects of Finite Matching Layers and Groundplane

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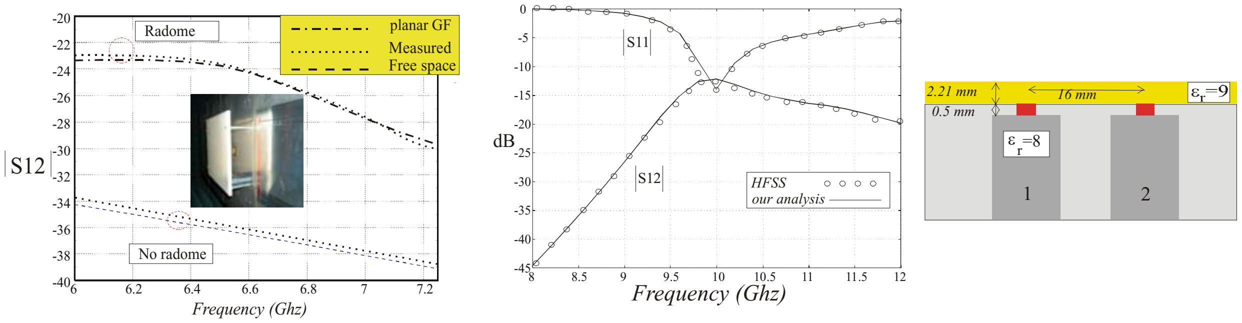
Abstract -- **In this contribution we present a high-frequency model to describe the reflections of surface waves at the edges of a truncated and grounded dielectric stratification. This model can eventually be integrated with an existing model that is able to analyse realistic finite open-ended planar waveguide arrays. This latter model has proven to be an accurate, efficient and flexible CAD tool [1]. Although the effects of surface waves are taken into account in that model, it cannot account for their reflections due to truncated dielectrics. Matching superstructures on top of arrays best prevent the support of surface waves, however, to get to an optimum design, a tool is necessary to validate and understand the impact of these surface wave reflections on the element input impedance. This contribution presents a first step to the extension of the software package in order to allow the analysis of finite arrays considering not only a truncated ground plane for the exterior region, but, in addition, also including a finite superstructure. First results for aperture antennas with finite superstructures will be shown.**

I. INTRODUCTION

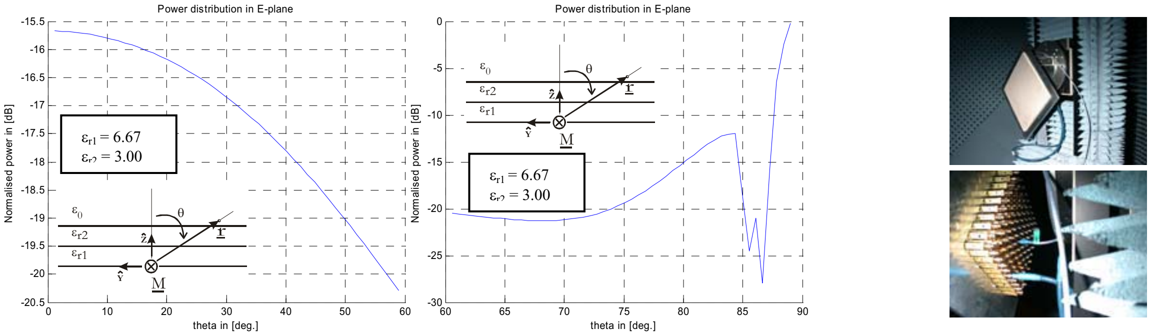
In many practical designs antenna arrays can be found consisting of less than a hundred elements. Also these arrays can be found to be mounted on the tightly fitting ground planes of their support structures and possibly they are covered with matching or protective layers on top of the array. These arrays can e.g. be found as multi-beam feeds for parabolic reflector antennas, antenna arrays in the noses of aircrafts or missiles. It is important to accurately describe the impact of these constructional constraints. Especially in these cases edge effects due to a truncated ground plane become important and the effect on the element reflection coefficients can be significant. The ability to accurately take into account the different effects can significantly reduce the fabrication time. TNO-FEL has developed models that can efficiently analyse open-ended waveguide arrays based on the MEN method [2]. In previous contributions a model has been presented to analyse planar finite arrays including the effect of a truncated ground plane, the latter effects were included in the model via an UTD approach.

At TNO-FEL the design of a hardware demonstrator has been completed which had to answer to rather stringent scanning requirements. In order to answer to these requirements the open-ended waveguide radiators had to be spaced in such a tight periodic lay-out that overlapping of the apertures occurred. To prevent this, the waveguides were dielectrically loaded creating a poor impedance match to half space. The use of a matching dielectric stratification on top of the array face alleviated this problem, however, at the cost of a smaller bandwidth. Now that measurements could be performed, they showed serious deviation from the simulations done with our code. Earlier evaluation trials with commercial software and measurements had shown that the simulations with our code concerning open-ended waveguides covered with a dielectric stratification were accurate (see Fig. 1a and b). It is very probable that the encountered deviations are due to the truncation effects of the dielectric layers. This assumption may be further strengthened by the results of an efficiency study that we performed for the pertinent array shown in Fig. 2b. The results of this study are shown in Fig. 2a and show a significant amount of energy confined within the dielectric stratification, enabling considerable energy to eventually be reflected from end points toward the apertures again. In order to solve this problem we introduced a high-frequency model to describe the reflections of surface waves due to the end point reflections from the truncated and grounded dielectric layers. This model will eventually be integrated in the existing model.



(a) (b)

Fig. 1 Plot of the mutual coupling between two C-band waveguides covered with a dielectric stratification (a), and a plot of the scattering parameters of two waveguides matched to free space with the use of an iris and dielectric slab (b). For (a) and (b) the comparison with respectively, measurement and commercial software, shows very good agreement. The reader is referred to [3] for details on both validation cases.



(a) (b)

Fig. 2 Circular near field scan at 10 GHz of the Poynting vector, at a fixed radius in the E-plane, due to an x-directed magnetic current source at ground plane level (a). Scan domain is split in two parts to retrieve enough samples inside the slab region, note that there is a considerable amount of energy trapped in the lower slab. In (b), the simulated layer stack is mounted on the real array.

II. THEORETICAL FORMULATION

The theoretical model for the analysis of finite arrays of open-ended waveguides on finite supporting structures is based on a Multi-mode Equivalent Network (MEN) representation of the radiating waveguides including their tuning elements and a high frequency approximation of the external region [1], [3]. In the external region, the additive contributions from the edge reflections of the finite substrate to the coupling matrix, which is generated by a standard Method of Moments approach for the infinite substrates, are computed depending on the position of the substrate edges.

III. FINITE GROUND PLANE

The magnetic field Green's function of a truncated metallic cylinder, describing the exterior region of the array with source and observation points on the planar truncation is not known analytically. However, it can be expressed as superposition of the grounded half space Green's function and a contribution that accounts for the truncation of the ground plane. The effect of the truncated ground plane is derived using an UTD approach. In this respect we can give evidence to the fact that since for the Green's function, both source and observation points are on the top of the considered cylinder, the ray tracing procedure turns out to be analytical. In practice, the procedure to be implemented for each couple of source-observation points involves: the determination of a number of flash points (one per wedge composing the polyhedral structure), the determination of the incident field (radiated by the source in presence of an infinite ground plane) in the flash points and the calculation of the pertinent UTD diffraction coefficients for every diffraction [4]. In their evaluation it is considered that in each flash point, the actual edge is substituted by an ideal infinitely extended edge locally tangent to the actual edge under analysis. In Fig. 3 the effect of the diffracted field on the mutual coupling parameter is shown, clearly there is an influence to account for, also when considering the radiation pattern.

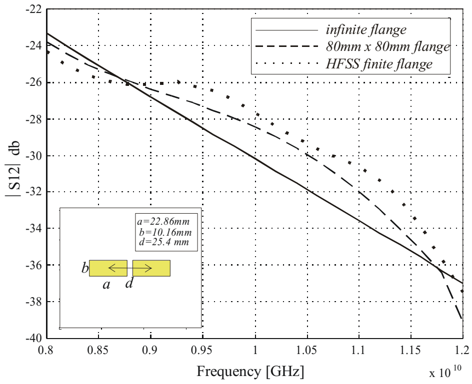


Fig. 3 Alteration of the mutual coupling coefficient due to the truncation of the ground plane

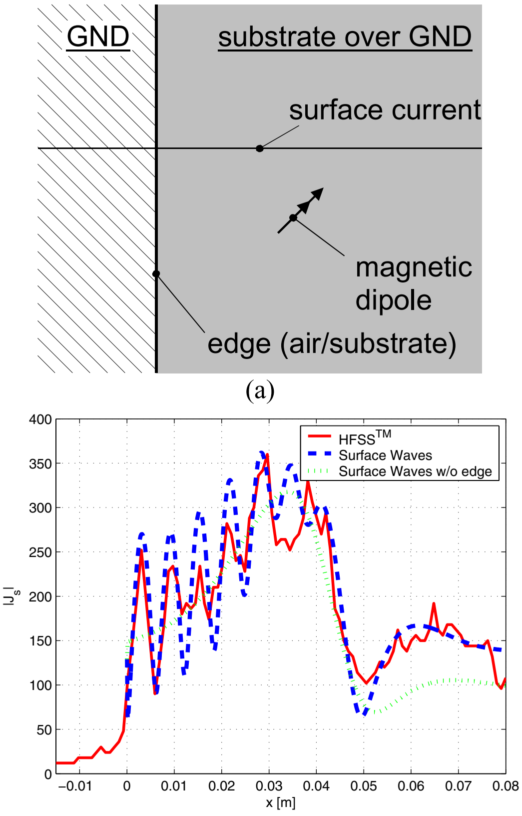
IV. Finite Substrate

The magnetic Green's function of a finite metal-backed substrate layer can be calculated as superposition of two contributions: $G = G^{inf} + G^{ref}$. G^{inf} is the standard magnetic Green's function of the metal-backed infinite dielectric slab and G^{ref} represents the effect of the sidewalls.

In a first step in the calculation of G^{ref} the properties of the surface waves excited by an infinitesimal magnetic dipole tangential to the ground plane have to be determined. Therefore, we consider the spectral domain formulation of G^{inf}, which exhibits several poles that are associated, depending on their location, to different types of radiated waves [5]. The amplitudes of the excited surface waves are given by the residue contributions of the associated poles in the inverse Fourier transform of the spectral Green's function. The radial propagation constants k_ρ of the TM and TE surface waves propagating at f along the substrate are found using a ray-tracing method and an optimisation algorithm.

The second step consists of the Geometrical Optics (GO) calculation of the magnetic field tangential to the ground plane generated by the reflected surface waves. This is done by application of image theory, assuming that the sidewalls can be approximated by piecewise straight parts. The corners where two straight edges of the substrate meet are treated separately. We presume that the corners are chamfered with an infinitesimal radius of curvature. This model accounts for the diffraction of surface waves at angular corners.

The correct treatment of the reflection of surface waves at a straight substrate edge was validated by a comparison with numerical calculations done using Ansoft HFSS. The geometry shown in Fig. 4a consists of an infinitesimal magnetic dipole at ground plane level that radiates in presence of a semi-infinite substrate with one straight edge. The magnitude of the surface current along a straight line (also shown in Fig. 4a) was calculated with our method and with HFSS. Both results are in good agreement. To show the effect of the edge, the current in case of an infinite substrate is plotted for comparison.



(a)

(b)

Fig. 4 (a) Geometry consisting of semi-infinite dielectric slab (ε_r = 12, h = 0.1 λ_0) on top of infinite ground plane (GND). Excitation by infinitesimal magnetic dipole on ground plane at f = 10 GHz with a distance of 40 mm from the edge; (b) Magnitude of surface current on ground plane along straight line shown in (a) at a distance of 10 mm from the source.

The proposed method was integrated into a MoM-based 2.5D software tool for planar microstrip circuits. Additive contributions to the coupling matrix generated by the MoM for the infinite substrates are computed depending on the position of the substrate edges. Using the enhanced tool the return loss of a microstripline-fed slot antenna with a thick dielectric overlay was calculated. The frequency dependence of the return loss for an infinitely extended substrate and for one and two substrate edges are shown in Fig. 5.

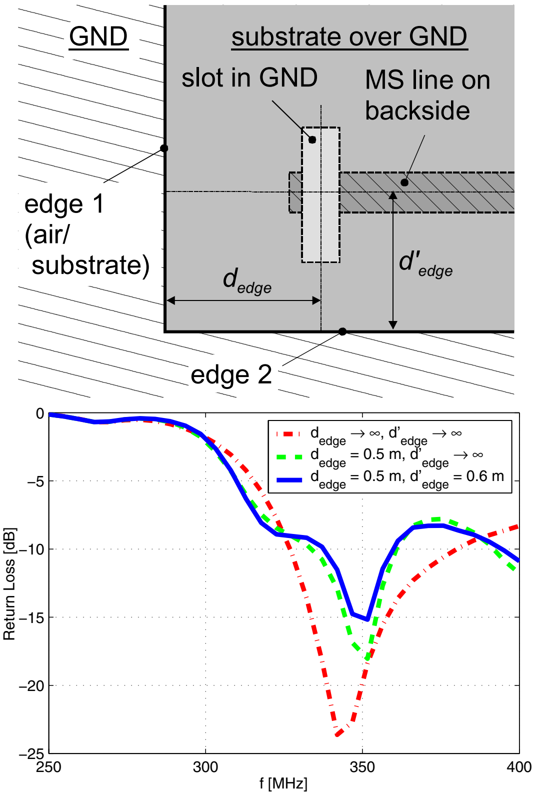


Fig. 5 Return loss of a microstripline-fed slot antenna with a finite dielectric overlay ($\varepsilon_r = 12$, $h = 63.63$ mm).

The simulations show that the substrate edge parallel to the slot has a significant impact on the return loss, whereas the second edge perpendicular to the slot has a minor effect only. This result can be explained by considering that, inside the substrate at the simulation frequencies, only the TM_0 surface wave can propagate and that TM surface waves are excited mainly in the direction perpendicular to the slot.

V. CONCLUSION

We have proposed an approximate method that enables the simulation of aperture antennas covered by a finite planar substrate. The method is based on a GO approximation of the reflection of surface waves from substrate edges. It has been validated in case of a magnetic dipole at ground plane level and numerical results for a single aperture antenna have been presented. This model will eventually be integrated in an existing software tool for realistic finite open-ended planar waveguide arrays. The tool will then be able to handle arrays with finite dielectric substrates covering the apertures.

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