Influence of a truncation of a dielectric structure on the mutual coupling between microstrip antennas

Vladimir A. Volski(1), Guy A.E. Vandebosch(2)

(1) KATHOLIEKE UNIVERSITEIT LEUVEN,
Faculteit Toegepaste Wetenschappen,
Departement Electrotechniek,
ESAT-TELEMIC,
Kasteelpark Arenberg 10,
B-3001, Leuven-Heverlee, Belgium
E-mail: vladimir.volski@esat.kuleuven.ac.be

(2) As (1) above,
E-mail: guy.vandebosch@esat.kuleuven.ac.be

ABSTRACT

The mutual coupling between microstrip patch antennas located on a semi-infinite dielectric substrate is calculated including the effect of the edge diffraction. The coupling between two microstrip antennas is expressed in terms of the coupling via so-called expansion waves. This step allows to separate the contribution of the edge diffraction from the direct coupling. The contribution of the edge diffraction is obtained using the numerical solution of an auxiliary problem: diffraction of the expansion wave at the truncation of a semi-infinite dielectric structure. The numerical results are presented for mutual coupling in the H-plane.

INTRODUCTION

Planar microstrip antennas have become a very popular and widespread type of antennas. Their large application area creates interest in the development of more powerful mathematical models, which are able to describe the real antenna configuration in all its details. Most of the existing models are based on the assumption that a ground plane has infinite dimension. These models have proved to be accurate in the prediction of self input characteristics and fairly good in the prediction of the radiation characteristics in the direction of the main beam. They can give no information about the influence of the finiteness of the ground plane on the calculated parameters. In recent years new models have appeared which are able to overcome partially this shortcoming. Some of these methods take into account the influence of a finite ground plane on the input parameters and the radiation pattern but most of them estimate only a distortion of the radiation pattern by the finite ground plane. In this paper we focus our attention on the influence of the truncation of a dielectric structure on the mutual coupling between two microstrip antennas. Up to now there are few papers dealing with this subject. The mutual coupling between microstrip antennas on a finite ground plane was investigated experimentally [1]. A theoretical analysis of the mutual coupling is a very complex problem. There is no analytical solution available and as a consequence numerical approaches are used. The direct numerical approach leads to the volume integral equation (VIE) technique [2,3]. This technique calculates the surface currents on the conductors (e.g. the finite ground plane) and the polarization currents in the dielectrics using the MoM formulation to solve the appropriate integral equations (surface/volume integral formulation using the equivalence principle). The currents are expanded in known basis functions with unknown amplitudes. The main shortcoming of this approach is that the calculation time and memory requirements increase with the size of the layer structure. As a consequence this approach is not very suited even for small antenna arrays. In the case when there is no dielectric an approach based on the postulates of the geometrical theory of diffraction (GTD) has proved its efficiency. Using this approach mutual coupling between two rectangular waveguides located close to the edge is investigated in [4]. This approach fails for non-homogeneous structures. Our method allows to partially overcome this shortcoming. It is based on the combination of the postulates of the geometrical theory of diffraction (GTD) and the integral equation technique. The two microstrip antennas have to be located not too close to the edge in order to ensure the correct application of GTD. The calculation is split into several steps. In the first step, we consider an infinite ground plane.
A complete calculation of all parameters is performed. The fields in the dielectric are calculated using the Expansion Wave Concept (EWC) [5]. The field excited by any source located in the vicinity of the dielectric layer structure can be expanded into a limited number of expansion waves (surface and space waves). The nature of these waves is determined by the dielectric structure and does not depend on the type of source. Each source excites the expansion waves with definite amplitudes. These waves propagate in the dielectric structure up to the edge where they diffract and reflect. In the second step, the diffraction coefficients for these waves at the edges of the ground plane are obtained numerically by using the integral equation technique. In the last step, the mutual coupling between the two microstrip antennas is calculated by using the GTD with the diffraction coefficients derived in the second step. The main advantage of our formulation in comparison with the VIE technique is that the diffraction effects are taken into consideration, separately from the primary source contribution like in the GTD. This approach is simpler and it is compatible with existing models for microstrip antennas. The calculation time is determined by the time needed to analyze the microstrip antenna on the infinite substrate and the time required for the calculation of the diffraction coefficients. The complete calculation time does not depend directly on the size of the ground plane. Numerical results showing the influence of the distance between two microstrip antennas on the mutual coupling in the H plane are presented.

**FORMULATION**

The general configuration is shown in Fig.1. Two microstrip probe-fed patch antennas are located at the distance \( d \) from the edge of a semi-infinite dielectric structure.

In the first step we consider a single patch antenna on an infinite ground plane. Using the MoM numerical procedure a current distribution on the patch is found. As soon as the current distribution is known we can calculate fields above and in the dielectric structure. After some distance from the patch the fields in the dielectric structure can be expanded in a finite number of expansion waves [5]

\[
\begin{align*}
\{E_\alpha\} = & \sum_{s=1}^{N} A_s \left\{ C^s(\rho_1) C^{*s}(z) \right\} \left\{ W'(\phi) \right\} e^{-j\rho_1 \phi}, \alpha = x, y, z
\end{align*}
\]

(1)

The expressions are in a cylindrical coordinate system \((\rho_1, \phi, z)\) with the origin at the position of the patch. They are valid inside the dielectric structure and at the air – dielectric structure interface. The number of expansion waves \( N \) depends on the layer parameters. In most practical 3D configurations with not too large thicknesses it is sufficient to use only 4 expansion waves: 1 TM surface wave, 2 TM space waves, and 1 TE space wave. The expansion wave formulation can be applied to any structure, homogeneous or non-homogeneous. The amplitude of the expansion wave \( A_s \) and its angular
dependency $W'(\phi)$ are determined by the planar configuration embedded inside the infinite dielectric structure [5]. The $\rho$ and $\rho_1$ dependencies of the expansion waves are determined only by the dielectric structure and they are independent of the configuration considered. $P$ is the propagation constant of an expansion wave.

Let’s consider now a semi-infinite structure. The expansion waves (1) will propagate up to the edge where they diffract. We can connect the diffracted expansion waves with the incident expansion waves (1) via diffraction coefficients $D$ in the same way as it is done in the GTD. In the case of the homogeneous structure

$$H^d = H^{inc} D_h \left( \frac{\rho_1}{\rho + \rho_1} \right) e^{-jk_0 \rho}$$

(2)

where $H^{inc}$ is the incident field at the edge, $k_0$ is the free space wavenumber and $D_h$ is a diffraction coefficient. Because we are far from the reflection and shadow boundaries we can use the diffraction coefficient the plane wave incidence.

$$D_h = \frac{e^{-\pi/4}}{2 \sqrt{2\pi k_0}} \frac{1}{\sin \alpha} \frac{1}{\cos \frac{\phi}{2}}$$

(3)

The situation becomes more complicated when the structure is non-homogeneous. In this case the analytical expressions for the diffraction coefficients are not available and we have to derive them numerically. The derivation of the diffraction coefficients is based on integral equation (IE) techniques and on the equivalence principle. The basic idea of how to calculate the diffraction of the surface or space wave at the truncation of the dielectric structure was introduced in [6]. Using the equivalence principle the space is split into several regions by introducing the unknown surface magnetic current backed by a conducting wall in the plane perpendicular to the dielectric structure. The condition of continuity of tangential magnetic field components yields integral equations (IE) for the magnetic current, which are solved using the Galerkin procedure. In general, each incident expansion wave produces several diffracted expansion waves. For example, the incident surface wave produces not only the diffracted surface wave but also the space waves. The ray tracing procedure is also more complex than in the homogeneous case. Due to the fact that the propagation constant of the incident wave $P^{inc}$ and the diffracted wave $P^{diff}$ may differ, the incident angle $\alpha$ is not always equal to the diffracted angle $\beta$ (see Fig.1). They are connected with each other via an equation similar to Snell’s law of refraction

$$P^{inc} \cos \alpha = P^{diff} \cos \beta$$

(4)

When the propagation constants of the incident wave and the diffracted wave are different, the radius of curvature of the diffracted wavefront $\rho^M$ at the edge is different from the radius of curvature of the incident wavefront $\rho_1$ at the edge.

$$\rho^M = \rho_1 \left( \frac{P^{refl}}{P^{inc}} \right) \frac{\sin^2 \beta}{\sin^2 \alpha}$$

(5)

The expressions (4,5) are similar to the expressions used in the calculation of the refracted ray tube in a semi-infinite dielectric medium [7]. The diffracted component of the field can be written in the following form

$$H^{diff} = H^{inc} D^{diff} \left( \frac{\rho^M}{\rho + \rho^M} \right) C^{diff}(\rho) e^{-jk_0 \rho}$$

(6)

where $C^{diff}(\rho)$ is the $\rho$-dependency of the 2D expansion waves [6]. The proposed approach has such a form that (6) goes smoothly to (2) when the structure changes smoothly from non-homogeneous to homogeneous. The last step in the calculation of the mutual coupling between two microstrip antennas consists of a combination of the direct coupling with the coupling via the edge (6) using the ray tracing procedure.

**NUMERICAL RESULT**

In order to illustrate the proposed algorithm we have considered a 15-element array of square probe-fed microstrip patches (2.75x2.75cm). The working frequency is 2.4GHz and the wavelength in free space is $\lambda=12.5$cm. The patches are located on a dielectric substrate with relative permittivity $\varepsilon_r=4.6$ and thickness $h=3.2$mm at the distance $d=25$cm ($2\lambda$) from the edge. The distance between elements in the array is $8$ cm ($0.64\lambda$).
The numerical results are shown in Fig.2. The mutual coupling in the H plane is calculated between the first element and the others for two cases: without edge diffraction (solid line) and with the edge diffraction (dashed line). Although the patches are quite far from the edge, the ripples due to the edge diffraction are clearly visible. This behavior is very similar to [4].

CONCLUSIONS

The mutual coupling between microstrip patch antennas is calculated including the edge diffraction. The numerical results show that edge diffraction may have a severe influence on the mutual coupling.

REFERENCE