Analysis of Planar Structures by an Integral Multi-Scale Approach

M. Nadarassin, H. Aubert and H. Baudrand

Laboratoire d'Electronique, E.N.S.E.E.I.H.T, 2 rue Camichel, 31071 Toulouse Cedex, FRANCE

Abstract

A Multi-scale Integral Method based on the intermediate basis concept is proposed. This method is particularly well-adapted to the rigorous determination of the impedance viewed by an active element placed on a complex circuit of small dimensions which is itself integrated on a large planar structure. A patch including a small circuit is characterized.

Introduction

In recent years, there is increasing interest in the study of hybrid devices which are composed of lumped elements (active component) integrated in a large circuit [1,5]. This class of structures is often used in the design of active antennas, because of numbers of advantages offered by this combination [2].
The approaches adopted in the literature in the treatment of these types of configurations lie essentially on empirical methods, approximate models or measurements, which do not often take into account the effect of the coupling between the different elements, the structures are divided into two domains, and analysed separately. Although some contributions [5] deal with a rigorous full-wave approach in some hybrid configurations, the active element is not integrated in the radiating surface but connected through the dielectric to this surface.
In this paper, a rigorous full-wave method is presented, the entire structure is studied with the concept of intermediate function basis, which acts as a bottleneck (Fig.1.). In other words, only few modal expansion terms of this basis are sufficient to yield good results for the impedance, since the complex circuit and the whole planar structure have dimensions of different scales. This approach was applied to a patch antenna including a source connected to the radiating surface by microstrip lines (Fig.2.). This study is completed by an analysis of the behaviour of the impedance as a function of the feeding element location.

Formulation

In order to describe clearly the theoretical developments of the method, let us consider a hybrid patch including a source connected to the radiating surface by microstrip lines (Fig.2.) and define four function bases (f_m), (h_p), (g_k) and (ξ_i) associated respectively with the domains D_1, D_2, D_3 and D_4 (Fig.3.). The classical approach in analysing an excited structure consists in writing the integral equations obtained from the boundary conditions verified by the tangential fields on the plane of metallization. These integral equations are transformed into a linear matrix system by the Galerkin procedure:

$$[Z][I]=[V_0] \qquad (1)$$

Where $Z_{pq}=\sum_m \langle \phi_p, f_m \rangle Z_m \langle f_m, \phi_q \rangle$ and the inner product is given by $\langle u,v \rangle = \int_{\text{patch surface}} u.v^* ds$

(* denotes the complex conjugate)
_(f_m) represents the modes TE_x and TM_x, and Z_m the total modal impedance associated with this vector [6].
_(ϕ_p) designates a trial function and I_p the unknown coefficient of this function to be determined.

Finally $V_{0p}=\langle \phi_p, e_0 \rangle$, where e_0 is the excitation term.

The direct resolution of this matrix system is not adapted to the study of multi-scale structures. Thus, it seems judicious to introduce an "intermediate function basis" (g_k) in the formulation of the initial boundary problem. This approach is based on successive change of basis and is formally similar to those adopted in the analysis of cascaded waveguide discontinuities. The first discontinuity is constituted of a source placed on a small guide (basis (g_k)) and the second one constituted of the aperture of this guide in free space (patch domain). Thus, we proceed in two steps:

1. In this basis (g_k), we can determine the matrix representation [Y] of an operator $\hat{Y}$, which takes into account the presence of the large planar structure (Fig.4).

2. We terminate the circuit (Fig.5.) by $\hat{Y}$ represented in this basis, and then solve a new inhomogeneous system.

Expression of the admittance operator $\hat{Y}$. Intermediate basis

In fact, the operator $\hat{Y}$ is obtained easily, we just have to change the right-hand side of (1), where each g_k (k=1 to N) is taken as the excitation source e_0. Consequently, for N vectors of the basis (g_k), we have N currents J_k:

$$J_k = \sum_p a_{kp} h_p \ , \ k = 1 \text{ to } N \qquad (2)$$

From the calculated current (2), we can deduce an admittance operator $\hat{Y}$. This one represents the external domain viewed by the small circuit. So by a change of basis, this operator is described in the basis (g_k). The matrix element Y_{kl} is given below:

$$Y_{kl} = \frac{\langle g_k , J_l \rangle}{\langle g_k , g_k \rangle} \qquad (3.a)$$

$$Y_{kl} = \sum_p a_{lp} \langle g_k , h_p \rangle . \langle h_p , g_l \rangle \qquad (3.b)$$

Thus, we can reduce the analysis to the small circuit as long as the termination conditions are contained in $\hat{Y}$. J' (Fig.5.) is the current density in the small line, and is expanded in the basis (ξ_i), e_0 is the excitation source (delta gap voltage source) (4) placed on the line (Fig.2.):

$$e_0 = \delta(y - y_0).\delta(z - z_0).\hat{z} \qquad (4)$$

The last equation is similar to (1), where the expression of the matrix elements of Z and V_0 are given in (5) and (6), consequently the current is determined and the input admittance is calculated according to (7).

$$Z_{ij} = \sum_{k,l} \langle \xi_i , g_k \rangle [Y]_{kl}^{-1} \langle g_l , \xi_j \rangle \qquad (5)$$

$$V_{0i} = \langle \xi_i , e_0 \rangle \qquad (6)$$

$$Y_{in} = \frac{\langle E, J' \rangle}{\langle E, E \rangle} \qquad (7)$$

where E is the electric field on the source.

Results

The circuit dimensions are c= 19.mm , b= 19.mm , c_1=7.mm, b_1= 5.mm , d_z=1.5mm, d_y=1.1mm, ε_r=4.7, d=0.2mm (Fig.3.) and h= 0.635mm (Fig.2.). 32 functions of the basis (h_p) are taken to expand the current on the patch. But a good convergence of the results is obtained with only one term of the basis (g_k). This last remark confirms the fact that a precise description of the field in the small domain is not necessary as long as the domains concerned have dimensions of different scales. Fig.6. and Fig.7 show the variations versus frequency of the real and imaginary parts of the impedance. We can note the shift inductance due to the transmission line and to the interaction between the small circuit and the rest of the structure, so the impedance does not necessarily become negative. This fact appears when the feeding element is located at the edge of the structure.

Conclusion

This method has been found to be a promising technique in rigorous treatment of complex structures . The application of this approach to a hybrid patch antenna has been proposed and confirmed by using an intermediate function basis. In fact, one term of this basis is sufficient to yield good results in impedance and consequently reduce the computation time. This approach could further be extended to a large class of circuits, like those which include diodes or transistors.

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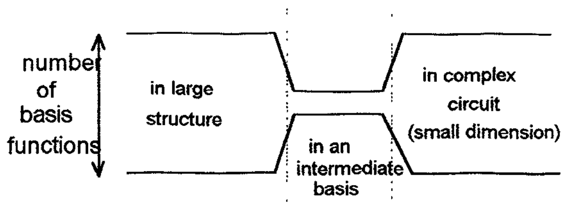

Fig.1. Analysis by intermediate basis.

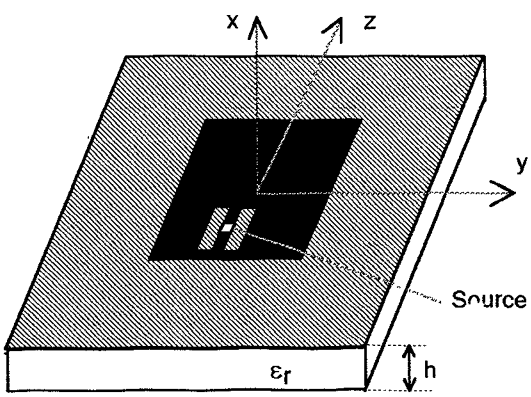

Fig.2. Patch antenna with a small circuit

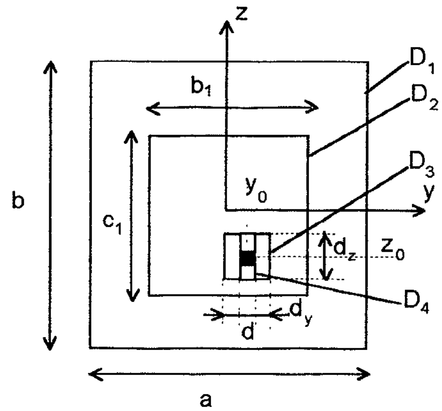

Fig.3. Description of the different domains. inserted.

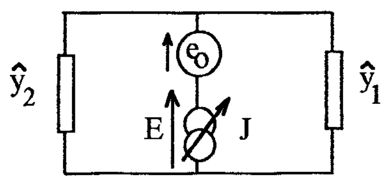

Fig.4. Equivalent circuit..

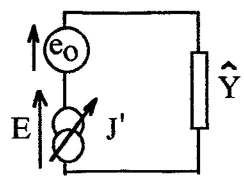

Fig.5.Equivalentcircuit

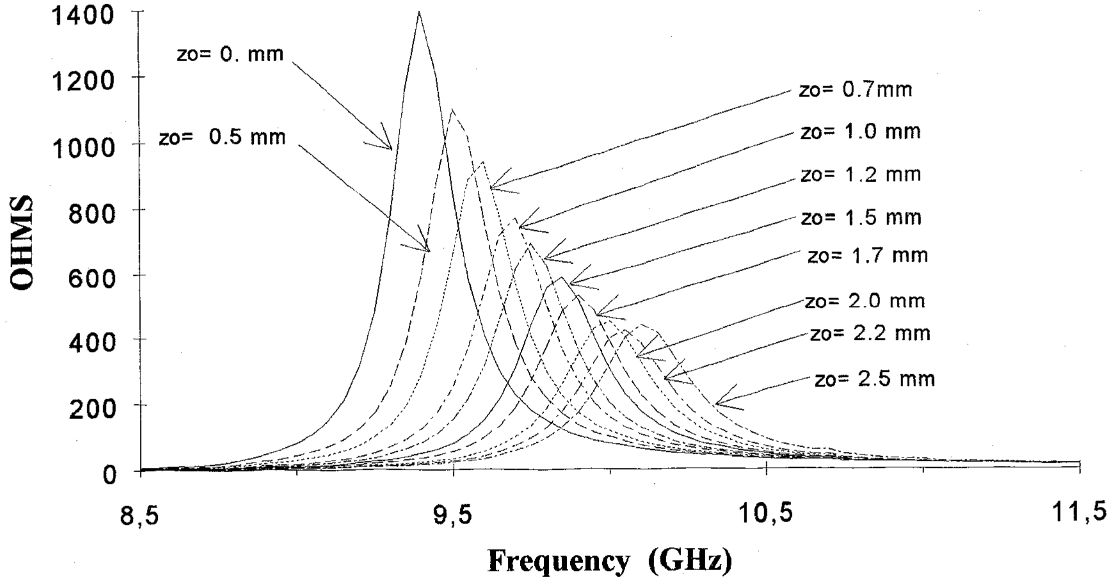

Fig.6. Real part of impedance, y_0= 0.mm, for different values of z_0.

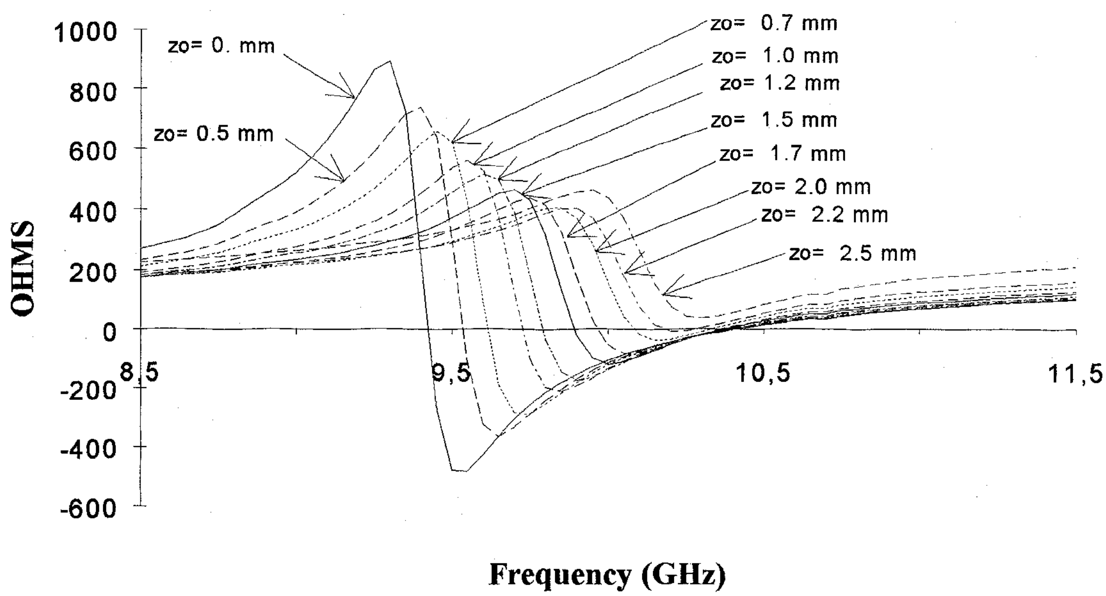

Fig.7. Imaginary part of impedance, y_0= 0.mm, for different values of z_0.