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Full-Wave Analysis of a Shielded Microstrip Dipole Using a New Formulation of The Moment Method

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ABSTRACT

An original integral method based on the moment method with an excitation term is developed in this paper to study a planar shielded dipole. The Generalized Equivalent Circuit (GEC) method is used to model the problem and then deduce an electromagnetic equation based on the impedance operator. For validation purposes, the developed method has been applied to describe the current behavior along the propagation direction and the input impedance.
For validity purpose, obtained results are compared to those obtained by commercial softaware, and good agreement isshown.
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Key words : Impedance operator, input impedance, MoM, GEC, shielded dipole.

1. INTRODUCTION

Themethod of moments (MOM) [1], which is one of the most commonly used numerical techniques for solving electromagnetic problems, is based upon the transformation of an operator equation into a matrix equation. While the computation of the matrix elements in the MOM can be carried out relatively efficiently when the medium involved is free-space, the introduction of a substrate material backed by a ground plane can render this task extremely time-consuming because of the need to compute the Somerfield's integrals appearing in the Green's functions.
One approach to circumventing this difficulty is to combine the Generalized Equivalent Circuit (GEC) to the Moment Method (MoM) [2, 3] In this formulation, the impedance operator is used instead of the integro-differential operator [4] simplifying then the transition between spectral and spatial domains.
The developed method has been applied to solve electromagnetic equation for a shielded microstrip dipole located in the cross section of a rectangular waveguide.

2. STUDIED STRUCTURE

Microstrip lines are characterized by their compatibility with others passive or active microstrip structures. They are used in various applications such as the realization of the couplers, filters…
The studied structure, as described in Figure 1, is a short-circuited planar microstrip line excited by a voltage source E0 placed on the circuit plane. This structure, supposed lossless, is embedded in a metallic waveguide whose cross section corresponds to the shape of the circuit. The boundary conditions are defined by the four electric walls of the waveguide which is open to infinity.
The characterization is made by modeling current density with appropriate set of trial functions.

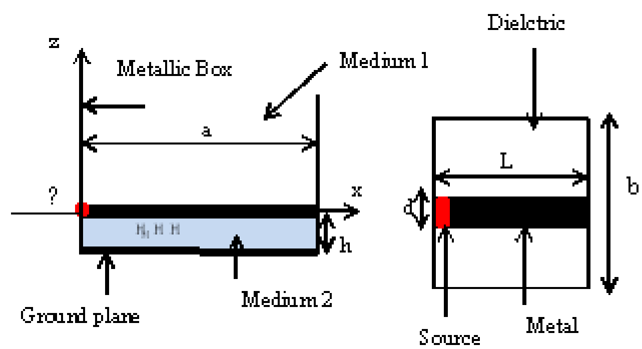

Figure 1:A short-end microstrip line
$f = 5.4GHz, w = 1mm, \delta = 0.75mm, d = 54mm \approx \lambda_0, L = 54mm \approx \lambda_0, h1.25mm,$
$\varepsilon_r = \varepsilon_0 = 1(vacuum).$

3. STRUCTURE MODELING

The studied problem is modeled using the GEC method [5] which translates the boundary conditions and the relations between electric and magnetic fields into an equivalent circuit, as shown in Figure 2.
The boundary conditions of magnetic field are translated in this representation by the Kirchhoff law applied to the electric field [6].
The relation between the electric field and the current is identified using the impedance operator. In fact, when we apply the laws of tension and current, we deduce the relation between virtual and real sources and its duals.

Thus, we can reformulate the original problem which is to research the current J flowing in the equivalentcircuit. To do this, we bring the differentmodes propagating in space on the surface of study and we transfer the vacuum into a dipole representing the admittance of vacuum. The same applies to the ground plane is replaced by a dipole representing the admittance of the short circuit.

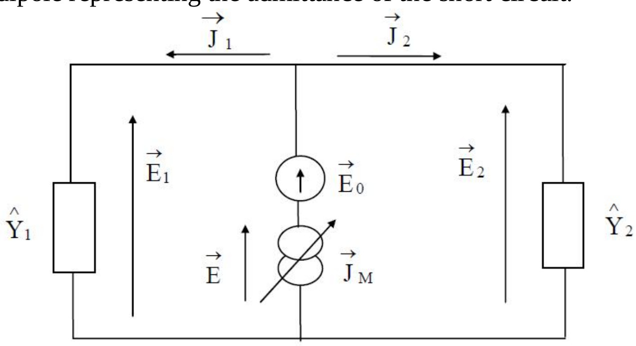

Figure 2: Equivalent diagramm of the microstrip dipole

$\hat{Y}_1$ is the operator of the short circuit admittance brought to the surface of the dielectric.

$\hat{Y}_2$ is the operator of the vacuum admittance reduced to the surface of the dielectric.

E_1 and E_2 define the field of both sides of the surface of the microstrip line.

$\vec{E}_0$ is the electric field introduced by the excitation source located in a planar subdomain of the microstrip line.

J_M is the current density on the metal part of the structure.

From this circuit, we can deduce the following equation:

$$E_0 + E = \hat{Z} J_M , \qquad (1)$$

where

$$\hat{Z} = (\hat{Y}_1 + \hat{Y}_2)^{-1} . \qquad (2)$$

4. THE MODIFIED MOMENT METHOD

The first step in the computation process is evaluation of the term $\hat{Z} J_M$. Some transformations are needed in order to compute this term.

The impedance operator used here is described using modal basis, it is a discrete operator applied on the spectral domain. It is also called a spatial-spectral operator and it allows transition from spectral to spatial domain. It is defined by:

$$\hat{Z} = \sum_{m,n} \left| f_{m,n} \right\rangle z_{m,n} \left\langle f_{m,n} \right| = \sum_{m,n} \left| f^{TE}_{m,n} \right\rangle z^{TE}_{m,n} \left\langle f^{TE}_{m,n} \right| + \sum_{m,n} \left| f^{TM}_{m,n} \right\rangle z^{TM}_{m,n} \left\langle f^{TM}_{m,n} \right| , \qquad (3)$$

where

$$f_{m,n}(x,y) = \begin{cases} f^{x}_{m,n}(x,y) = N_x \cos\left(\frac{m\Pi}{a} x\right) \sin\left(\frac{n\Pi}{b}\left(y + \frac{b}{2}\right)\right) \\ f^{y}_{m,n}(x,y) = N_y \sin\left(\frac{m\Pi}{a} x\right) \cos\left(\frac{n\Pi}{b}\left(y + \frac{b}{2}\right)\right) \end{cases} \qquad (4)(4)$$

areorthonormal basis functions, on which will be projected the current density. This basis is chosen as the solutions of the transverse electric field of a homogeneous metallic waveguide.

At this stage, we can project the unknown J_M (current) on the basis of trial functions and then write:

$$\overrightarrow{J_M}(x,y) = \sum_{k=1}^{k=Nessai} X_k \vec{g}_k(x,y) \qquad (5)$$

On the basis of modes functions, J_M is written as follows:

$$\vec{J}(x,y) = \sum_{p}^{NBFE} \left[\left(\sum_{m,n}^{NBFB\_TE} x_p \langle \vec{g}_p, \vec{f}^{TE}_{m,n} \rangle \vec{f}^{TE}_{m,n}(x,y) \right) + \left(\sum_{m,n}^{NBFB\_TM} x_p \langle \vec{g}_p, \vec{f}^{TM}_{m,n} \rangle \vec{f}^{TM}_{m,n}(x,y) \right) \right] , \qquad (6)$$

and the electric field is written as:

$$\vec{E}(x,y) = \sum_{p}^{NBFE} \left[\left(\sum_{m,n}^{NBFB\_TE} x_p \langle \vec{g}_p, \vec{f}^{TE}_{m,n} \rangle Z^{TE}_{m,n} \vec{f}^{TE}_{m,n}(x,y) \right) + \left(\sum_{m,n}^{NBFB\_TM} x_p \langle \vec{g}_p, \vec{f}^{TM}_{m,n} \rangle Z^{TM}_{m,n} \vec{f}^{TM}_{m,n}(x,y) \right) \right] . \qquad (7)$$

We can compute the input impedance by the evaluation of

$$Z_0 = \frac{\langle E_0 | E_0 \rangle}{\langle E_0 | J_M \rangle} . \qquad (8)$$

The solution must satisfy the following requirements: $\vec{E} = \vec{0}$ on the metal and $\vec{J}_M = \vec{0}$ on the dielectric.

We use the Galerkin method to solve the Eq. 1 numerically. The method consists in determining the system matrix from the equivalent circuit, and to make projections based on test functions.

The resulting matrix equation is written in this form:

$$\begin{pmatrix} \langle \vec{g}_1 | \hat{Z} \vec{g}_1 \rangle & \dots & \langle \vec{g}_1 | \hat{Z} \vec{g}_N \rangle \\ \vdots & \ddots & \vdots \\ \langle \vec{g}_N | \hat{Z} \vec{g}_1 \rangle & \dots & \langle \vec{g}_N | \hat{Z} \vec{g}_N \rangle \end{pmatrix} \begin{pmatrix} X_1 \\ \dots \\ X_N \end{pmatrix} = \begin{pmatrix} \langle \vec{g}_1 | \hat{Z} E_0 \rangle \\ \dots \\ \langle \vec{g}_N | \hat{Z} E_0 \rangle \end{pmatrix} . \qquad (9)$$

Due to the rectangular shape of the microstrip line, the trial functions are sinusoidal entire domain functions [7, 8]. The inner products are computed and stored in the memory, and then the study of the planar structure becomes easy.

5. NUMERICAL RESULTS

Computer programs were developed in MATLAB to implement MoM method combined to GEC modeling to analyze the studied structure.

A study of convergence is performed to verify the stability of the method. Figure 3 shows the convergence of the input impedance in the direction of propagation.

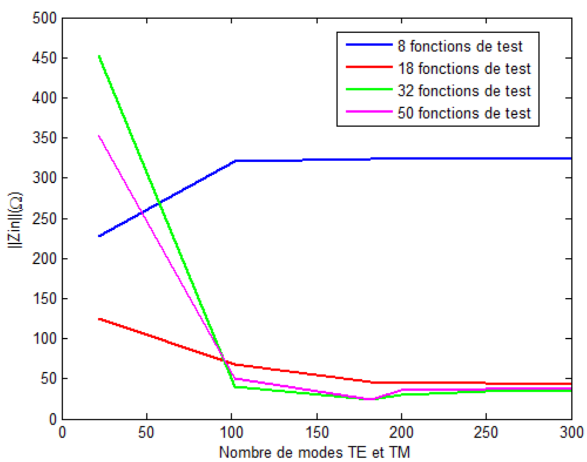

Figure 3: Variation of ||Zin|| in function of modes number for different number of trial functions at $f = 5.4$ GHz, $w = 1$ mm, $\delta = 0.75$ mm, $d = 54$ mm $\approx \lambda_0$, $L = 54$ mm $\approx \lambda_0$, $h = 1.25$ mm, $\varepsilon_r = \varepsilon_0 = 1$.

In this case, beyond 32 trial functions and 300 modes the result stabilizes.

We studied the input impedance seen by the excitation source for frequencies ranging from 2 GHz to 12 GHz and we compared our results with those found by SONNET and published by [8]. Figure 4 shows a good agreement between the two results. We can deduce the values of the resonance frequencies.

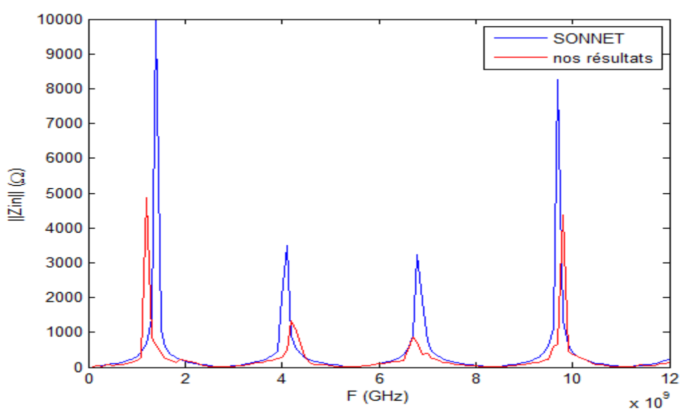

Figure 4: Variation de $||Zin||$ in function of frequency.

The three-dimensional representation of the current density in the direction of propagation Jx (x, y) obtained using sinusoidal functions, we can see that the current density well verifies the physical criteria regarding the form of the physical current. Indeed, the current component along the propagation direction satisfies conditions "end line": it is maximum at a short-circuit (contact with a magnetic wall).

Since the line width is negligible (of the order of λ_g / 54), the current does not vary in the transverse direction.

We note also from Figure 5 and Figure 6 the current behaves as a nearly perfect sine function λ_g period = 54 mm.

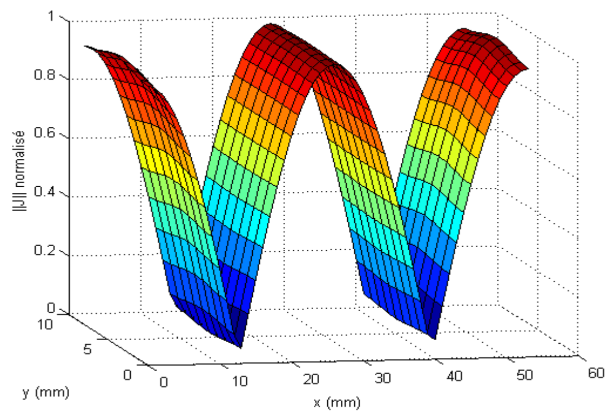

Figure 5: 3-D representation of the current along (ox) direction.

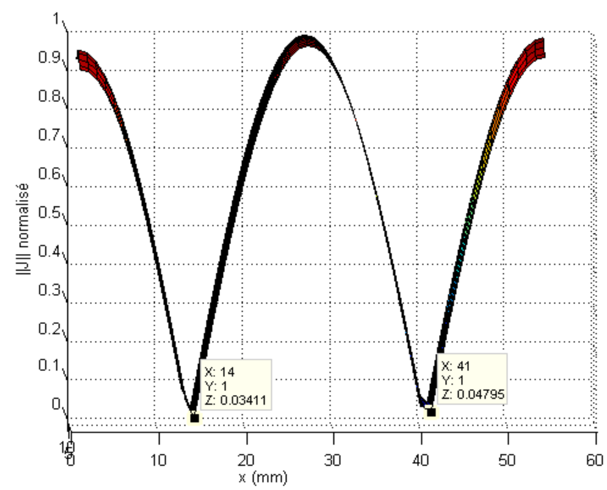

Figure 6: Sinusoidal behavior of the current density

6. CONCLUSION

A new formulation of the moment method was presented in this paper to solve an electromagnetic problem. The conventional moment method was combined to the generalized equivalent circuit modeling to get an original and simple but rigorous formulation. This technique is based on the impedance operator and is applied to analyze short-end microstrip line on a rectangular waveguide. The obtained equation was expressed as a function of the impedance operator which is a spatial-spectral operator allowing an easy transition from spectral to spatial domain.

The current, the electric field behaviors and the input inpedance have been determined using this method. For validation purposes, the computed results were compared to those obtained by the commercial software SONNET.
The primary area of future work is to use wavelet expansion as trial functions for this method toremedy the problem of the density matrix generated by the classic moment method.

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