3rd International Conference on Automation, Control, Engineering and Computer Science (ACECS'16)
Proceedings of Engineering & Technology (PET)
pp. 755-760

Rigorous Study of a microstrip line excited with perpendicular coaxial source using MGEC MoM based Method

Basma OUESLATI#1, Taha BEN SALAH#2, Chiraz LARBI#3, Taoufik AGUILI#4

#SYS'Com Laboratory, National Engineering School of Tunis ENIT
BP. Le belvedere 1002, Tunis, TUNISIA
[1]basma.oueslati@gmail.com
[2]taha.bensalah@gmail.com
[3]chiraz.aguili@gmail.com
[4]taoufik.aguili@enit.rnu.tn

***Abstract*— This paper describes a new approach based on the MGEC method [1] which should enable analyzing circuits in different plans. In this study, we consider an excitation source of type coaxial cable localized in a perpendicular plan to the circuit. This type of excitation requires manipulating MGEC method in full 3D context. The originality of this work is the introduction of new operators expressing transformations from one plan to another.**

***Keywords*— MoM, 3D structures, coaxial source, discontinuity, MGEC**

I. Introduction

In the literature, various techniques have been developed for the characterization of discontinuities in planar circuits [2, 3, 4, 5, 6, 7, 8, 9, 10 and 11]. In these methods, several types of excitation sources where used in order to guarantee an acceptable coherence and efficiency as to better describe the theoretical formulation. This problem was first raised in 1985 by Janson [12]. He explains the difficulty of finding a natural formulation for the term excitation [13]. Indeed, the introduction of a source makes the boundaries conditions verification more difficult in its vicinity.

Because of its simplicity, the method of moments (MoM) [2] is often used for solving such problems (MGEC being one of its applications). However, MoM takes only into account the planar excitation sources incorporated in the same plan as the circuit. Actually, sources are either perpendicular to the circuit plan or are put in the ground plan level. In both cases, excitation should be modeled in a different plan than the circuit. Here where the 2.5D MoM method find its limits.

To simplify this problem most studies model the excitation source as a localized planar element that is integrated in the same plan as the circuit.

Hence the importance of our study as we propose a more accurate modelling by taking into account the excitation source plan. In fact, our new approach allows modelling different planar structures irrespective of the source localization plan. Real coaxial cable the excitations located in a perpendicular plan, from the one hand, or the line coaxial excitations located at the ground plan, on the other hand, are to be better expressed and modeled. In this paper, we consider excitation by coaxial cable.

Our approach is based on the definition of new admittance operators for connecting the excitation source to various electrical quantities. These new operators are used to model the electric field and current density at the circuit plan by means of three-dimensional transformations describing the passage from one plan to another.

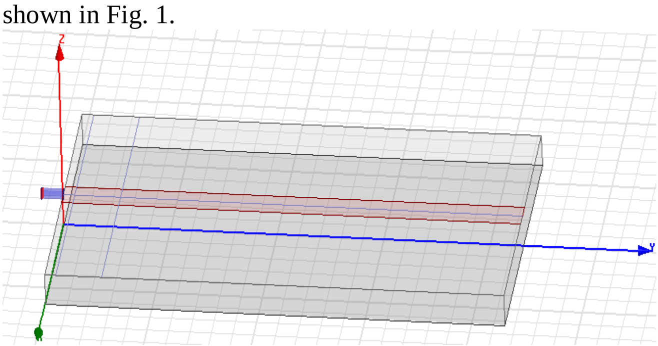
Next paragraph is an introduction to the new formulation and calculation of the different operators in the case of a coaxial source located at the perpendicular plan to the circuit. Then, we will present various simulation results with our new formulation. Finally, we validate results by means of comparison with commercial software HFSS.

II. New Formulation

Coaxial cable is widely used as excitation source. We will take this case as a concrete example of source located in a perpendicular plan to the circuit. To avoid discontinuity between the source and the circuit, we take as an expression of the source, the fundamental mode of coaxial cable (quasi-TEM) [14, 15].

This source is defined by a unitary function $|e_1(x,y)>$, where: $<e_1 | j_1>=1$ and $| j_1>$ is the current density relative to $| e_1(x,y)>$ on the plan (xoy).

To validate our numerical approach, we consider a microstrip line short-circuited at a distance l from the source as shown in Fig. 1.



ISSN: 2356-5608

Fig. 1 Microstrip short-circuited line

Dimensions are detailed in the Table 1:

TABLE I
STUDY STRUCTURE DIMENSIONS

	length	width	height
Line	l=λ/4	w=2mm=0.023 λ	-
dielectric	l=λ/4	a=12.7mm=0.15λ	h_0=11.43mm=0.133λ
Box	l=λ/4	a=12.7mm=0.15λ	h=1.27mm=0.15λ

With: freq=3.5 GHz, ε_r=1

According to the method of generalized equivalent circuit MGEC associated to the MoM in order to establish relationship between the various electrical quantities of structure (E, J). We use circuit at Fig. 2 which depicts the equivalent circuit relative to the structure of Fig.1.

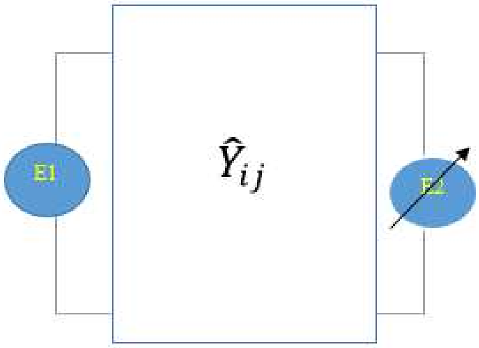


Fig. 2 generalize equivalent circuit of Microstrip short-circuited line

We consider here admittance operator. The electromagnetic quantities in the source plan and circuit plan can be written using the following relations:

$$\begin{cases} |J_1> = |\hat{Y}_{11}\, E_1> + |\hat{Y}_{12}\, E_2> \\ |J_2> = |\hat{Y}_{21}\, E_1> + |\hat{Y}_{22}\, E_2> \end{cases} \quad (1)$$

Where:
J_1: current density of source
E_1: electric field of source
E_2 and J_2 are the electric field and the current density defined in the plan of the circuit to study

The admittances operators $\hat{Y}_{ij}$ define the relationship between the electric fields of the TE and TM modes of jth plan and the current density generated by these modes on the ith plan. These $\hat{Y}_{ij}$ can be determined by applying the superposition theorem to the previous system and decomposing these operators on a homogeneous basis (TE and TM) associated with each one.

If f_{mn} and g_{pq} are the orthonormal basis of electric field and current density defined on the source and the circuit plans then we can write for i=1,2 and j=1,2

$$\hat{Y}_{ij} = \sum_{mn}\sum_{pq} |\, g_{pq}{}^{(i)}\rangle^{TE,TM}\, y_{mn,pq}{}^{TE,TM} \langle\, f_{mn}{}^{(j)}\,|^{TE,TM} \quad (2)$$

If i = j, $\hat{Y}_{ij}$ coincides with the admittance operator defined on the ith plan (i=1: vertical plan, i=2: circuit plan). In this case, we have $g_{pq} = f_{mn}$ and the equation (2) becomes:

$$\hat{Y}_{ii} = \sum_{mn} |\, f_{mn}\rangle^{TE,TM}\, y_{mn}{}^{TE,TM} \langle\, f_{mn}\,|^{TE,TM} \quad (3)$$

To determine the different electromagnetic quantities, we use a variant of moment's method that is the method of Galerkin [16]. The advantage of this method is the rapid convergence of his algorithm, because the computational effort is limited to the resolution of an integral equation expressing the boundary conditions of the electromagnetic fields on a section of the circuit.

We choose the test functions of electric field type $\varphi_i(x,z)$ that describes the electric field E. Its functions are assumed to be virtual sources defined in the circuit plan and must meet the boundary conditions of the circuit plan (xoz). They are zero on the metal and non-zero on the dielectric. The current density J is zero on the dielectric and non-zero on the metal.

In this basis, the electric field is expressed:

$$E = \sum_{k=1}^{K} x_k \varphi_k(x,z) \quad (4)$$

With:

$x_k (k = 1\,..K)$: Projection of E on this basis

K: the number of test functions necessary for the convergence of electric field E

The application of Galerkin to the system (1), consists of projecting the first equation on the function of unitary source$|\, e_{01}>$.

$$\langle e_{01} \,|\, J_1\rangle = \langle e_{01}\,|\,\hat{Y}_{11}\, E_1\rangle + \langle e_{01}\,|\,\hat{Y}_{12}\, E_2\rangle \quad (5)$$

Also, we project the second equation of the system (1) on the different test functions.

$$\langle \varphi_i \,|\, J_2\rangle = \langle \varphi_i\,|\,\hat{Y}_{21}\, E_1\rangle + \langle \varphi_i\,|\,\hat{Y}_{22}\, E_2\rangle,\ for\ i = 1\,..K \quad (6)$$

We assume that: $E_{01} = V_{01}\, e_{01}$ and $J_{01} = I_{01}\, j_{01}$

With $\langle e_{0i} \,|\, j_{0i}\rangle = 1$

Considering the relationship between the current density and the test functions, the resolution of equations (5) and (6) allows us to establish the expression of the y_{in} input impedance:

$$y_{in} = \frac{I_1}{J_1} = Y_{11} - C_1\, A^{-1}\, B_1 \quad (7)$$

With:

$$Y_{11} = \langle e_{01}\,|\,\hat{Y}_{11}\, e_{01}\rangle \quad (8)$$

$$A(i,k) = \langle \varphi_i\,|\,\hat{Y}_{22}\, \varphi_k\rangle,\ i = 1\,..K \quad (9)$$

$$B(j) = \langle \varphi_j\,|\,\hat{Y}_{21}\, e_{01}\rangle,\ j = 1\,..K \quad (10)$$

$$C(i) = \langle e_{01} | \hat{Y}_{12}\ \varphi_i \rangle, i = 1..K \quad (11)$$

To model the electric field, it is sufficient to determine the coefficients x_k of the test functions. The vector $X = (x_1, ..., x_k, ..., x_K)^t$ is written in the following form (12):

$$X = -\sum_i V_{oi}\ A^{-1}\ B_i \quad (12)$$

Using this new formulation of admittance operators $\hat{Y}_{ij}$ describing the passage of the source plan to the circuit plan (and vice versa) we have been able to evaluate input admittance y_{in} expression. The next paragraph is dedicated to validation of the presented formulation by deducing electric field and current density on the circuit plan.

III. Numerical results

Several admittances operators are used to perform the passage from one plan to another requiring several large-sized matrices manipulation and cpu-consuming integral calculations. Using generic tools such as MATLAB, lacks of fast hybrid symbolic/numeric calculation and has no built-in cache support neither save-points (to stop and resume calculation on need) concept. For these reasons, we considered using a TMWLib library (for Tiny MicroWave Library) developed by Dr Taha Ben Salah during his research work [17]. The library is based on Java/Scala programming languages, is fully modular, feature rich and scalable.

To validate the presented approach, we evaluate the input impedance y_{in} and compare it to the theoretical input impedance of a microstrip short circuited line. We also deduce some electromagnetic characteristics (current density J and electric field E) to verify boundary conditions.

A. The input admittance y_{in}

Figure 3 illustrates the simulation result of the input impedance y_{in} given by equation 7 and that of the theoretical input impedance of a line short circuited at a distance l from the source given by the equation 13.

$$y_{in}^{th} = -j\ \mathrm{cotan}(\beta\, l) \quad (13)$$

With β is the propagation constant of the fundamental mode.

The y_{in} curve is evaluated at convergence with 5 extended test functions (trigonometric type), 80000 TE and TM mode functions f_{mn} (source plan) and 54000 TE and TM modes functions (circuit plan) g_{pq}.

We notice that the two curves are quite similar confirming the validity of the presented formulation with a relative error of at most 1% with a slight difference between the two curves at the poles.

We also note that this result is consistent with theoretical expectations since we have used the fundamental mode of a coaxial cable as an excitation source which explains this perfect matching between source and dipole.

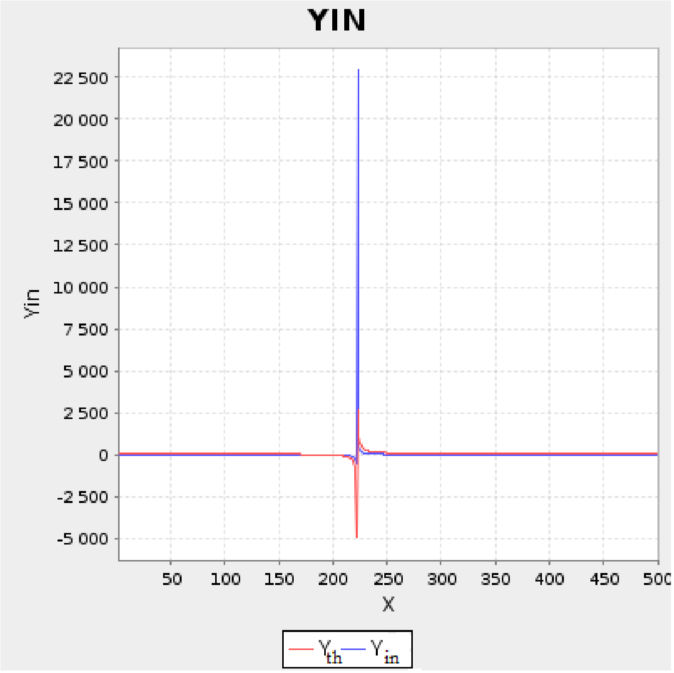


Fig. 3 The input admittance y_{in} comparison

B. Electromagnetic characteristics

We consider now the electromagnetic field projected on the TE and TM mode functions (equation 14) and the current density (equation 15) in three cases: MGEC'3D (our new approach), traditional MGEC (with a planar source) and HFSS (source modal).

$$E = \sum_{p,q}^{N_g} \sum_{i=1}^{K} x_i \langle g_{pq}^{TE,TM} | \varphi_i \rangle\ g_{pq}^{TE,TM} \quad (14)$$

$$J = \sum_{p,q}^{N_g} \sum_{i=1}^{K} x_i \langle g_{pq}^{TE,TM} | \varphi_i \rangle\ y_{pq}^{TE,TM}\ g_{pq}^{TE,TM} \quad (15)$$

With:

$g_{pq}^{TE,TM}$: TE and TM mode functions in the circuit plan (xoz)

$y_{pq}^{TE,TM}$: TE and TM mode admittance at the short-circuit (y=-h) and ($y=h_0$)

$$y_{pq}^{TE} = \frac{\gamma_{pq}}{j\,\omega\,\mu}\ \mathrm{cotanh}(\gamma_{pq}\ h_i) \quad (16)$$

$$y_{pq}^{TM} = \frac{j\,\omega\,\varepsilon_i}{\gamma_{pq}}\ \mathrm{cotanh}(\gamma_{pq}\ h_i) \quad (17)$$

γ_{pq}: The propagation constant of a mode $g_{pq}(x,z)$, such as :

$$\gamma_{mn}^2 = (\frac{m\,\pi}{a})^2 + (\frac{n\,\pi}{h_i})^2 - \omega^2\ \varepsilon_i\ \mu_0 \quad (18)$$

Where:

$$\begin{cases} \varepsilon_i = \varepsilon_0\ \varepsilon_r;\ h_i = -h;\ for\ -h \le y \le 0 \\ \varepsilon_i = \varepsilon_0;\ h_i = h_0;\ for\ 0 \prec y \le h_0 \end{cases}$$

1) Electromagnetic field E:

Figures 4 and 5 provide a comparison of the results of the normalized electric field Ey (field in the direction of propagation) at the microstrip short-circuited line between the new approach and results gathered using HFSS commercial simulation software.

Figure 4 illustrates a section along the axis (oy). We observe that the two curves have the same envelop shape (regardless of Gibbs effect fluctuations), a maximum at the source then it follows a rapid attenuation moving away from the source.

Figure 5 presents a section along the axis (ox). We observe that the new technique results still coincide with Commercial Software ones while defining a smaller bandwidth which can be considered as more accurate for such a structure.

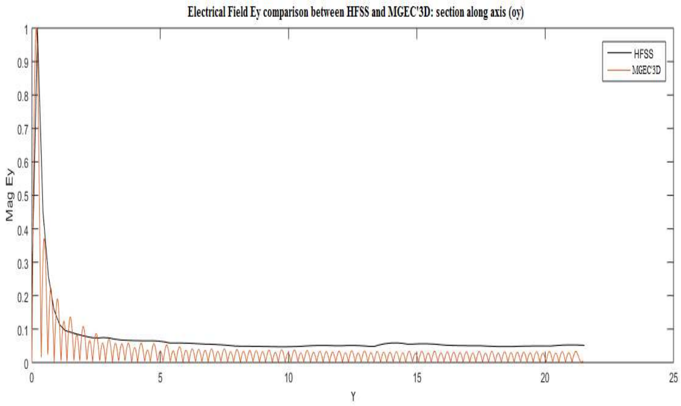


Fig. 4 Electrical field Ey comparison between HFSS and MGEC’3D: section along axis (oy)

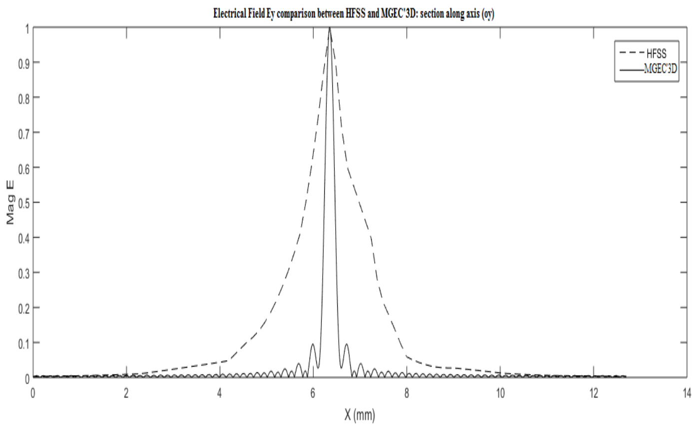


Fig. 5 Electrical field Ey comparison between HFSS and MGEC’3D: section along axis (ox)

Figure 6 illustrates that the electric field E_x is maximum at the level of discontinuity and is zero elsewhere with concordance to boundary conditions.

Fig. 6 Electrical field Ex with MGEC’3D

2) Current density

Figures 7 and 8 illustrate shapes of the current density (MGEC'3D and in HFSS). New technique behaves more smoothly and more symmetric due to chosen rooftop x-only test functions.

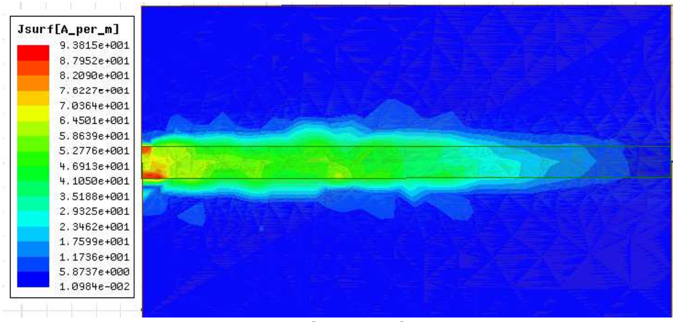


Fig. 7 Current density with HFSS

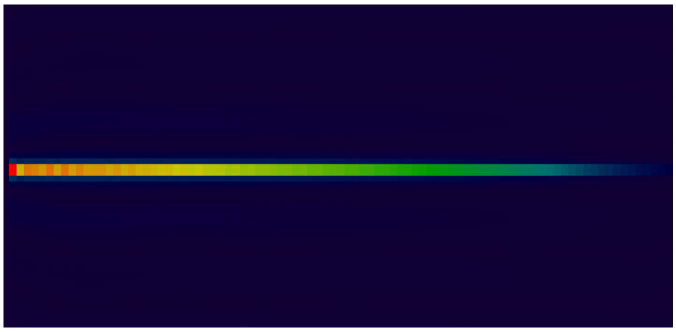


Fig. 8 Current density with MGEC’3D (coaxial source)

IV. Conclusions

We proposed in this paper a new formulation of the MGEC method to help studying planar structures excited by coaxial sources located at a perpendicular plan. We introduced a new formulation based on new admittance operators and three-dimensional transformations to depict the transition from one plan to another. We applied the approach to a microstrip short-circuited line for validation and compared input impedance results to theoretical input impedance of the same structure to get a 1% relative error.

We also determined the current density and the electric field and compared them with ones obtained with the commercial software HFSS.

References

[1] R.F. Harrington, “time Harmonic electromagnetic Fields”, Mac Graw Hill, 1961

[2] Silvester P., Benedek P., “Microstrip discontinuity capacitances for right-angle bends, T junctions and crossing”, IEEE trans., MTT, vol. 21, Dec. 1973, pp. 1036-1042

[3] El Gouzi, M. E. A. and M. Boussouis, “Hybrid method for analyse discontinuities in shielded microstrip,” International Journal of Engineering Science and Technology, Vol. 2, No. 7, 2010.

[4] Baudrand H., “Tridimentional method in monolithic microwaves integrated circuit”, SMBO Brazilian symposium NATAL, July 88, pp 183-192

[5] Worm S. B., “A full wave analysis of discontinuities in planar waveguides by the method of lines using a source approach”, IEEE, Trans., MTT, vol. 38, n10, oct. 1990, pp 1510-1513

[6] Gil I. M., Zapata J., “Efficient singular element for finite element analysis of quasi-TEM transmission lines and waveguides with sharp metal edges”, IEEE, Trans., MTT, vol. 42, January 1994, pp.92

[7] Marcysiak M. C., GWAREK W. K., “A transformed symmetrical condensed mode for the effective TLM analysis of guided wave problems”, IEEE, Trans., MTT, vol. 41, n 5, May 1993, pp. 820

[8] Baudrand H., “Representation by equivalent circuit of the integral methods in microwave passive elements”, EMC, Budapest (Sept 10/4/90)

[9] Arriviere H. J., Davis J. B., “The solution of electromagnetic eigenvalue problems by least squares boundary residuals”, IEEE, Trans., MTT, 23 May 1975, n 5, pp 436-441

[10] Riabi M., “étude de structures planaires par la méthode des moindres carrés modifiée”, 11ème colloque optiques hertziennes et diélectriques, Tunisie, Sept. 1991

[11] Nikoloask K., “Frequency-dependent analysis of a shielded microstrip STEP discontinuity using an efficient Mode-Matching technique”, IEEE, Trans., MTT 36, n6, June 1988, pp 976-984

[12] Koster N., Janson H., “The microstrip step discontinuity: A revised description”, IEEE, Trans., MTT, vol 34, n2, February 1986, pp 213-223

[13] Pujol S., Baudrand H., Hanna F., “A complete description of a source type method for modelling planar structures”, Ann telecom 48, n 9-10, 1993, pp 459-470

[14] M. Golio, J. Golio, “RF and microwave passive and active technologies”, RF and Microwave Handbook, Second Edition

[15] Hitendra K Malik, A. K. singh, “Engineering physics”

[16] Aguili, T., “Modélisation des composants S. H. F planaires par la méthode des circuits équivalents généralisés,” Thesis, National Engineering School of Tunis ENIT, May 2000.

[17] T. B. Salah, “Etude des structures invariantes par échelles par une méthode intégrale multi modale combinée à la méthode de normalisation”, Thesis, National Engineering School of Tunis ENIT, February, 2009