EFFICIENT ANALYSIS OF MICROSTRIP RADIATION BY THE TLM INTEGRAL EQUATION (TLMIE) METHOD

Luca Pierantoni, Stefan Lindenmeier and Peter Russer

Technische Universität München, Lehrstuhl für Hochfrequenztechnik, Munich, Germany
Arcisstrasse 21, D-80333, München, Germany; phone: +49 89 289 23374
fax: +49 89 289 23365, e-mail: pieranto@hft.e-technik.tu-muenchen.de

Abstract

Microstrip lines are widely used in microwave and millimeter-wave integrated circuits [1,2]. In this contribution we present an accurate analysis of the e.m. near and far field radiated by a microstrip line. The e.m. analysis is developed by a novel method, the Transmission Line Matrix Integral Equation (TLMIE) method. This method combines the advantages of the TLM method, which is very flexible for the modeling of general structures with arbitrary shapes [3,4], and the advantages of the integral equation (I.E.) method, which allows to incorporate the treatment of large free space regions.

Introduction

Planar transmission structures are widely used in microwave, millimeter-wave circuits and high-speed digital circuits. These are, for example, striplines, microstrips and coplanar waveguides, [1,2]. Spurious radiation may occur at discontinuities of the microstrip lines. Moreover, it is a common situation that they can interfere with other devices or lines placed in the same environment, for example placed in the same dielectric substrate. To this purpose, the e.m investigation is particularly important in the time domain, where we have transient phenomena in response to an impulse excitation. In this case the analysis becomes more complicated, in particular when a lot of devices is present in the same environment. The presence of these impulsive fields provides a great amount of e.m. disturbance against which the microstrip should be immune. With that the analysis of the microstrip susceptibility becomes an important requirement for its design. In this contribution we present an accurate analysis of the e.m. radiation properties of a loop microstrip line. The analysis is developed by means of the novel hybrid Transmission Line Matrix-Integral Equation (TLMIE) method. The TLMIE method has been proven to be a powerful tool for solving EMC, EMI and general radiating problems [7]. Due to their high flexibility, the TLM/FDTD methods are excellently suited for field problems in structures of nearly arbitrary geometry [3,4]. On the other hand, they are suitable for the analysis of large free space regions because of the great waste of memory in the computational algorithm. The integral equation (IE) method permits us to incorporate the treatment of large free space regions with very high efficiency, because it reduces the complexity of a field problem by one dimension [5,6]. The integral equation method in connection with the method of moments approach is very powerful for the solution of a great variety of problems. However it requires for each particular class of structures a special analytical preprocessing of the problem. We

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have developed a novel hybrid method combining the advantages of a three-dimensional space discretization method, such as the TLM method, and the advantages of the I.E. method. By embedding the e.m. structures into discretized subdomains, very general geometric structures may be treated without special analytic preprocessing. As an example we show how the TLMIE method can predict the e.m. near field and far field of typical and complex radiating structures, involving two or more radiating substructures. In the TLMIE method the entire space of the problem is subdivided into subregions to which the different methods are applied. At the boundary interfaces of these subregions the transverse e.m. field is expanded by means of subdomain basis functions, as in the TLM or the FDTD scheme [3,4]. The expanded fields on the interfaces are then related to each other by the Green's function. Using the continuity of the fields we provide the appropriate set of EFIE and MFIE integral equations. These integral equations are then discretized following the method of moments approach. We derive a matrix system whose solution provides the unknown expanding coefficients of the total tangential field. The present method can be used for the analysis of general radiation problems.

Theory

We define a closed region which contains a structure with complex geometry and the open free-space region surrounding this closed region. These two regions are separated by an arbitrary surface S. We define the closed region as the TLM region because it is discretized by the TLM method. The TLM-region is coupled to the open region by means of the Green's function in the time domain. Inside the TLM-region there are sources. The field which is excited by the given sources produces an incident tangential field ${}^{TLM}\boldsymbol{E}_t^{inc}(\boldsymbol{r},t)$ and ${}^{TLM}\boldsymbol{H}_t^{inc}(\boldsymbol{r},t)$ at the interface S. This field is calculated by the TLM algorithm. Another incident field ${}^{fsr}\boldsymbol{E}_t^{inc}(\boldsymbol{r},t)$ and ${}^{fsr}\boldsymbol{H}_t^{inc}(\boldsymbol{r},t)$ is coming from the external free space region. By applying the continuity of the tangential fields on the interface, we derive the following Electric Field Integral Equation (EFIE), (1), and the Magnetic Field Integral Equation (MFIE), (1) as in [6]:

$$\boldsymbol{E}_t(\boldsymbol{r},t) = {}^{TLM}\boldsymbol{E}_t^{inc}(\boldsymbol{r},t) + \boldsymbol{E}_t^{r}(\boldsymbol{r},t) + {}^{fsr}\boldsymbol{E}_t^{inc}(\boldsymbol{r},t) \qquad (1)$$

$$\boldsymbol{H}_t(\boldsymbol{r},t) = {}^{TLM}\boldsymbol{H}_t^{inc}(\boldsymbol{r},t) + \boldsymbol{H}_t^{r}(\boldsymbol{r},t) + {}^{fsr}\boldsymbol{H}_t^{inc}(\boldsymbol{r},t) \qquad (2)$$

The fields $\boldsymbol{E}_t(\boldsymbol{r},t)$, $\boldsymbol{H}_t(\boldsymbol{r},t)$ represent the unknown total fields at the interface. The fields $\boldsymbol{E}_t^r(\boldsymbol{r},t)$, $\boldsymbol{H}_t^r(\boldsymbol{r},t)$ represent the fields radiated from the interface. The radiated field is derived as in [6,7] from the total tangential fields via free space Green's functions. The equations (1) and (2) can be written in a compact matrix form. In the following we refer only to the electric field; analogous considerations also hold for the magnetic field, as in [6,7]. For eq. (1) we have:

$$\boldsymbol{E}_t(\boldsymbol{r},t) = {}^{TLM}\boldsymbol{H}_t^{inc}(\boldsymbol{r},t) + {}^{fsr}\boldsymbol{E}_t^{inc}(\boldsymbol{r},t) + \qquad \textbf{(3)}$$

$$\tilde{\boldsymbol{C}}_e(\boldsymbol{r},\boldsymbol{r}',t-\tau)\boldsymbol{E}_t(\boldsymbol{r}',\tau) + \tilde{\boldsymbol{C}}_h(\boldsymbol{r},\boldsymbol{r}',t-\tau)\boldsymbol{H}_t(\boldsymbol{r}',\tau)$$

where the matrices $\tilde{\boldsymbol{C}}_e$, $\tilde{\boldsymbol{C}}_h$ represent operators involving integral and differential operations, according to the form of the radiated field of equations (1) and (2). The vectors **r** and **r**' are the destination and source position vectors, respectively. The points **r**' are defined on the radiating interface. The integral equation (3), has a time-retardation feature τ=(r-r´)/c that allows us to solve them in an iterative way. Since the variable τ is always less than t, the unknown field $\boldsymbol{E}_t(\boldsymbol{r},t)$ and $\boldsymbol{H}_t(\boldsymbol{r},t)$ is the sum of the known incident field and an integral that is also known from the past history of the same fields. With that we derive the basis for solving integral equations by iterative methods, [6,7]. Now we discretize the IE by expanding the tangential fields with an appropriate set of functions:

$$\boldsymbol{E}_t(\boldsymbol{r},t)=\sum_{m'=1}^{M}\sum_{n'=0}^{N}\boldsymbol{E}_\varphi\left(\boldsymbol{r}_{m'},t_{n'}\right)P(\boldsymbol{r}-\boldsymbol{r}_{m'})T\left(t-t_{n'}\right) \quad (4)$$

In eq.(4) Φ and Ψ are surface pulse functions of rectangular type, being equal to unity for $\boldsymbol{r}$ on the elementary surface centred at $\boldsymbol{r}_{m'}$. P and Q are time-pulse functions, being equal to unity for t in the time interval centered at $t_{n'}$. We consider M elementary subdomains and N time steps. $\boldsymbol{E}_\varphi$ and $\boldsymbol{H}_\psi$ are the unknown expanding coefficients. Now we apply the Method of Moments, as in [6]. For obtaining a matrix system we give numbers to the coordinates of the fields: m, m', m'' are numbers of the discrete coordinates $\boldsymbol{r}, \boldsymbol{r}_{m'}, \boldsymbol{r}_{m''}$ and n, n', n'' are numbers of the discrete time steps $t, t_{n'}, t_{n''}$. Now, by inserting eq. (4) in (3) and taking the symmetric product with the weighting functions as in [6,7],we derive:

$$\boldsymbol{E}_\varphi(m,n)={}^{TLM}\boldsymbol{E}_t^{inc}(m,n)+{}^{fsr}\boldsymbol{E}_t^{inc}(m,n)+$$
$$\sum_{m'=1}^{M}\sum_{n'=1}^{n-1}\left\{\tilde{\boldsymbol{K}}_e^E(m,m';n-n')\boldsymbol{E}_\varphi(m',n')+\right.$$
$$\left.+\tilde{\boldsymbol{K}}_h^E(m,m';n-n')\boldsymbol{H}_\psi(m',n')\right\} \qquad (5)$$

The equation (5) constitutes an equation system whose solution permits us to recover iteratively the expanding coefficients of the field. The matricies $\boldsymbol{K}$ involve integral and differential operations. The same eq.(5) shows that, for every cell of number m, the expanding coefficients at time n can be directly computed from the incident field at the same time and the past history of the tangential field in all the cells. This process is called marching-on-in-time method [6,7]. Moreover, the total tangental field provide the exact value of the boundary condition for the TLM algorithm.

Example

We consider a microstrip line having the form of a loop as indicated in Fig.1. We excite by a z-directed electric pulse of gaussian-type, with amplitude E_0. The ecitation is placed at the boundary, as depicted in Fig.1.

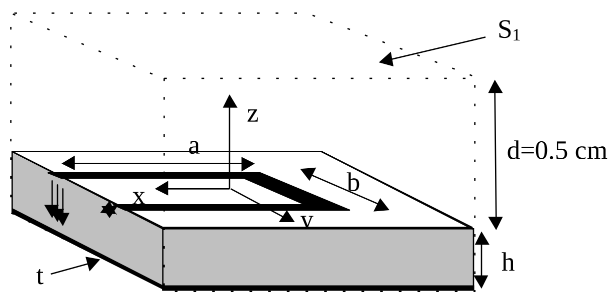

Fig1. The analized microstrip line. Parameters: a=0.5 mm, b=0.55 mm, t=25 μm, h=125 μm, s=75 μm, ε_r=10.

We place the front plane of the microstrip at the plane z=0. In Fig.1 is depicted the surrounding imaginary rectangular box where the two methods are matched. The upper plane of the surface S_1 is placed at a distance of z=250 μm from the plane z=0. The solution of the problem coinsists to find out the distribution of the tangential field on the surfaces of interfaces. Once this distribution is known we can evaluate the surrounding field directly by the Green's function.

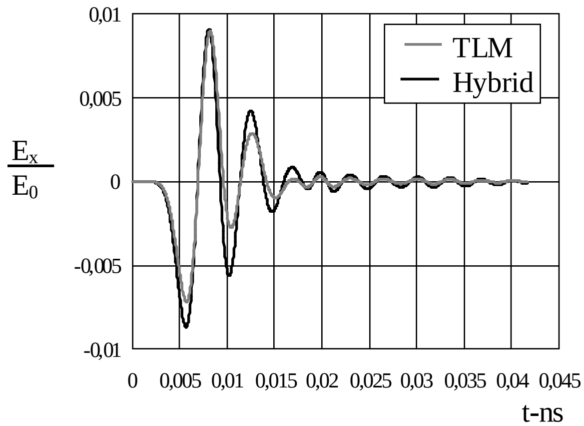

Fig.2. Time evolution of the electric field E_x by the TLMIE and TLM method at z=125 μm.

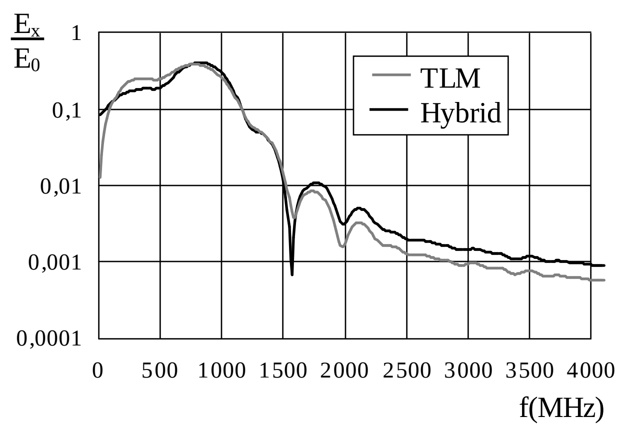

Fig.3. Frequency evolution of the electric field E_x by the TLMIE and TLM method at z=125 μm.

We calculate the radiated near field at the point z=125 μm, in the normal direction, by the hybrid TLMIE method. Then, for a self consistent comparison, we calculate the same field by the pure TLM method. This is possible by enlarging the 3-D spatial domain of the TLM method and by applying absorbing boundary conditions. The dimension of the TLM cell is dl=25 μm. In Fig.2 we compare the E_x field (normalized with respect to E_0), evaluated by the TLMIE method and by the pure TLM method, respectively, in the time domain.

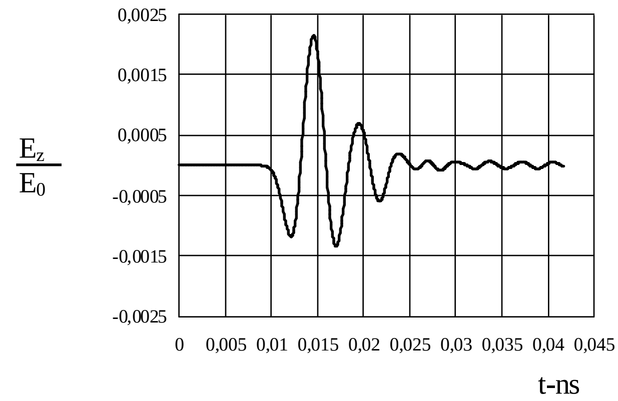

Fig.4. Time evolution of the electric field E_x by the TLMIE method, at z=2.5 mm.

In Fig.3 we report the same comparison in the frequency domain, after a FFT. In both cases we observe a very good agreement. Then we evaluate the the far field with the TLMIE method, outside the imaginary surrounding box. Usually the evaluation of the far field is very inaccurate by the pure TLM-FDTD methods. In Fig.4 we reporte the evaluation of the E_x field at z=2.5 mm, by the TLMIE method.

Conclusions

We presented the development of the novel hybrid Transmission Line Matrix-Integral Equation (TLMIE) method combining the advantages of both methods. The TLM method is very flexible for modeling general structures with arbitrary shapes. The Integral Equation method allows us to incorporate the treatment of large free space regions. The present method is applied for an accurate analysis and prediction of the e.m. field of a microstrip line. The near field results which are calculated by the TLMIE method are compared with results calculated by the pure TLM method, showing very good agreement.

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