A GENERALIZED MOM-SPICE ITERATIVE TECHNIQUE FOR FIELD COUPLING TO MULTICONDUCTOR TRANSMISSION LINES IN PRESENCE OF COMPLEX STRUCTURES

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Abstract: A generalized MoM-SPICE iterative technique for field coupling analysis of multiconductor transmission lines in the vicinity of complex structures is presented. Telegrapher’s coupling equations are modified with additional distributed voltage and current sources for more accurate analysis of the total current induced onto the transmission lines in presence of complex structures. These additional voltage and current sources are introduced to modify the classical telegrapher’s coupling equations beyond the quasi-static regime. The surrounding structure is modeled via the Method of Moments and SPICE is used to simulate equivalent circuit model of the multiconductor transmission lines extracted via the PEEC method.

I. INTRODUCTION

Electromagnetic field coupling from ambient radiation onto multiconductor transmission lines has been studied extensively. The primary approach to the problem is to modify telegrapher’s classical equations by incorporating additional voltage and current sources to model the external excitation fields [1]-[5].

There are three predominant approaches to transmission line analysis depending on the interpretation of the excitation terms [1], [2], [3]. These approaches are limited to the cases where quasi-static conditions are met and yield fairly good results when the closest distance between the conductors and the ground plane is less than one tenth of the smallest wavelength [4]. In other words, these methods yield accurate results for relatively low frequency analysis where the quasi-static approximation is known to yield reasonably good results [7], [8]. As can be expected, methods based on the Transmission Line Technique (TLT) do not account for self-radiation of the transmission lines (i.e. they neglect the common mode current). That is, TLT can only predict the differential mode current, but for more general structures, we need to also include the common mode current to better characterize the total current induced on the transmission lines. The common mode currents are not an issue when the lines are very close to the ground plane. In this case, only the differential mode is dominant and consequently the quasi-static approximation is valid [9].

To improve the TLT approximation by accounting for common mode currents, a technique that modifies telegrapher’s coupling equations with additional iterative source terms was proposed in [10] for a finite conductor over a perfectly conducting infinite plane. Also, Haase [9] proposed an iterative transmission line method, employing the generalized form of the telegrapher’s equations. However, validation of the technique in [9] was done for non-uniform multiconductor lines over a perfectly conducting flat plate.

In this paper, we propose a more general approach for handling complex multiconductor transmission lines with SPICE and nearby structures via the Method of Moments (MoM). An iterative method is then used to handle the interaction between the structures and transmission line bundles. A unique aspect of our formulation is that both the quasi-static and non-static effects are included. This is accomplished by introducing Telegrapher’s coupling equations derived in presence of complex structures. In this case, non-static terms are included as corrective iterative sources to enforce the boundary conditions and continuity equation. In other words, we propose a general set of equations which are consistent with the physical insight of the phenomena. Our approach can be considered as a generalization to the formulation given in [10], where only a single transmission line above an infinite ground plane was considered.
II. THEORY

To generate the generalized TLT equations, vector potential in tangential electric field boundary condition is decomposed into quasi-static and non-static term. A similar approach is also followed to derive the non-static contribution of scalar potential used in the equation of continuity. Consequently, non-static terms appear as additive correction source terms in the classical TLT equations. The new TLT equations are:

\[
\frac{d[V_{\text{ref}}]}{dx} + j\omega[L][I] = [E_{\text{ref}}] - j\omega[A_{\text{ns}}]
\]

(1)

\[
\frac{d[I]}{dx} + j\omega[C][V_{\text{ref}}] = j\omega[C][V_{\text{ref}}]
\]

\[
[A_{\text{ns}}] = [A] - [L][I]
\]

\[
[C][V_{\text{ref}}] = \frac{d[I]}{dx} \frac{1}{j\omega} + [C][\Phi]
\]

(2)

where \(\Phi, A\) and \(A_{\text{ns}}\) refer to total scalar, vector and non-static vector potentials respectively. Also \(V_{\text{ref}}\) and \(V_{\text{ref}}\) refers to the potential difference between the TLs and ground plane. To solve (1) and (2), an iterative approach is taken to be called Telegrapher’s Iterative Coupling Equations (TICE):

\[
\left[ \frac{d[V_{\text{ref}}]}{dx} + j\omega[L'][I] \right]_{n} = [E_{\text{ref}}] + j\omega[A]_{n-1} - j\omega[L'][I]_{n-1}
\]

\[
\left[ \frac{d[I]}{dx} + j\omega[C][V_{\text{ref}}] \right]_{n} = \frac{d[I]}{dx} \frac{1}{j\omega} + j\omega[C][\Phi]_{n-1}
\]

(3)

where \(n\) is the iteration number and \(n=0\) refers to quasi-static solution. At every iteration, \([A]_{n-1}\) and \([\Phi]_{n-1}\) are computed from the potential integrals via a Multilevel Fast Multipole Method (MLFMM) code EMCAR (see [12]).

III. VALIDATION EXAMPLE

As a validation example, we consider a situation which is closer to reality. Specifically, we consider the geometry in Fig. 1. Four conductor transmission lines in the presence of a trough are analyzed and the results are given in Fig 2. Not surprisingly, the deviation of the quasi-static solution is substantial. Nevertheless, after five iterations, our solution is very close to the exact.

IV. DISCUSSION AND CONCLUSION

An iterative method for the analysis of multiconductor transmission lines in the vicinity of complex structures was presented. The employed pair of Telegrapher’s coupling equations was based on a generalization which allowed for the inclusion of additional sources (non-static contributions) to permit coupling between the surrounding structures.

A validation example was given which demonstrated that as the surrounding geometrical complexity increased. The resulting current distribution based on the quasi-static approximation was inadequate, implying a necessity for including the non-static effects.

REFERENCES


Fig. 1 Geometry of four conductor transmission lines in the vicinity of a trough.

Fig. 2 Current distribution along the light color transmission line for the geometry in Fig. 1 with $h_1=0.6\lambda$ and $h_2=0.6\lambda$. 