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Improvised PEEC Method in the Modeling of the Near-field Coupling with Electrical Cable

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Abstract— To study the susceptibility of these cables due to external electromagnetic (EM) perturbation, several numerical methods have been developed. This paper describes a technique for obtaining integrated near-field (NF) coupling Partial Element Equivalent Circuit (PEEC) model for the electromagnetic compatibility (EMC) issues. It incorporates EM coupling due to electronic components and cables with/without ground plane along with its capabilities of transforming field based problem into the circuit domain. Elementary dipoles are used to calculate the EM field, which represents modeling of electronic components radiation. The proposed approach is demonstrated by analyzing a cable above the ground plane and with elementary dipoles as source of disturbances. It is being carried over with Finite Element Method (FEM) and then Finite Integration Technique (FIT). The results obtained by both the methods are in good agreement. In order to validate the obtained results, the test set up is being built by analytical TLM models. The developments of 2D and 3D dimensional dipole are being integrated into the PEEC method. As perspective, coupling PEEC model could be developed considering inductive and capacitive coupling between the cable, ground plane and devices.

1. INTRODUCTION

In the modern automotive electronic system cables play a major role for the reliability due to the integration density. In power electronic system transmission and energy conversion, electrical cabling is an indispensable part. The advent of inexpensive memory and processing power also renders numerical methods very attractive. General numerical methods, such as the finite element method (FEM), the Method of Moments (MoM), and Finite-Difference (FD) methods, Partial Element Equivalent Circuit (PEEC) methods give acceptable accuracy when the size of the structure is not much larger than the excitation wavelength and the number of numerical unknowns is sufficiently small for present-day computers [1]. Unfortunately, these two requirements are often violated in real-world applications. Parallelization of numerical algorithms has achieved some success in extending modeling scale [2]. However, the required processing hardware is often not within easy reach of typical scientists and engineers.

This paper develops efficient hybrid method to overcome the difficulty of large simulation scale. This hybrid method can capture accuracy of exact numerical solvers on scales that far exceed their native capability. It also depicts the application of the hybrid method to a general large-scale EM modeling problem. The method must analyze the given structure and produce the required induced electrical components. The study setup is analyzed by dividing the structure into a number of small segments. In every simulation model, an analysis combines key information from previous models with knowledge about the coupling phenomenas and physical structure to apply proper inputs. This hybrid method employs many tools which are not new to the EM engineering/modeling discipline: radiated emission, FEM, finite-difference methods (FDM), field extraction and network analysis. The main contribution of this paper is the innovative combination of FEM methods and Analytical methods along with dipole source as perturbation source. The final significant contribution of this work is an extended understanding of time and frequency domain analysis and proposed methodology for full wave solution analysis.

2. HYBRID METHOD FORMULATION

In the calculation of radiated coupling with analytical model, the methodology has the above steps. Normally in the calculation of E and H field, we used to consider the total field to obtain the complete radiated field, whereas in the case of analytical method we are not obliged to include the scattering field due to the fact that the model is considered in the absence of the cable and also with the ground plane condition [3–5].

This proposed hybrid method considers the limitations posed by the previous researchers where the coupling between the cable and ground plane, the coupling between the dipole and cable and

then coupling between the dipole and ground plane are also considered for the calculation. Another advantage is that there is no need of matched load conditions in the calculation of coupling [6–8].

To study, the coupling between the cable and external electromagnetic field several numerical methods are developed and used to predict the disturbance induced on the cables; with the help of analytical formulations, it is possible to predict the voltage induced on the cable. These formulations are used to calculate the field excitation. The near-field coupling of a cable above the ground plane can be studied using differential techniques based on transmission line theory. In this study, we are representing the non-uniform electromagnetic field interference between electronic components and the cable when placed close to each other.

This model consists of three sections. In Section 1, it deals with radiation emission model; Section 2 with transmission line models; Section 3 deals with integration of PEEC models in the coupling modeling under study is examined. In this paper we focus on feasibility study of the PEEC implementation.

3. PEEC METHOD

The PEEC method, developed by A. Ruehli, is like the MoM based integral formulation of Maxwell's equations making the technique is well suited for free space simulations. The main feature with PEEC method is the combined circuit and EM simulation that is performed with the same equivalent circuit in both time and frequency domain [9–12].

The starting point of theoretical derivation is the total electric field, at the observation point expressed in terms of vector magnetic potential \vec{A} , and the scalar electric potential as:

$$E(\vec{r}, \omega) = -j\omega\vec{A}(\vec{r}, \omega) - \nabla\Phi(\vec{r}, \omega). \quad (1)$$

and the vector potential is given by:

$$\vec{A}(\vec{r}, \omega) = \mu \int_{v'} G(\vec{r}, \vec{r}') J(\vec{r}', \omega) dv', \quad (2)$$

where J is the volume current density at a source point \vec{r}' and G is the Green's free-space function:

$$G(\vec{r}, \vec{r}') = \frac{e^{-j\beta R}}{4\pi R}, \quad (3)$$

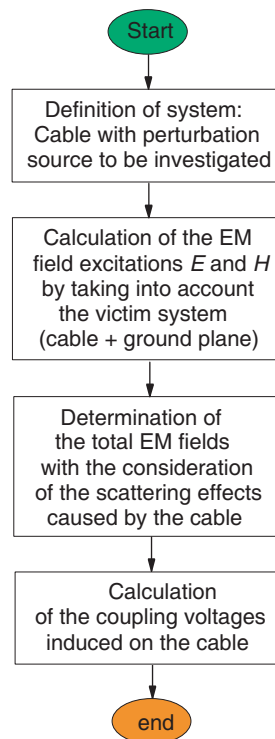


Figure 1: Flow chart summarizing the hybrid method under study.

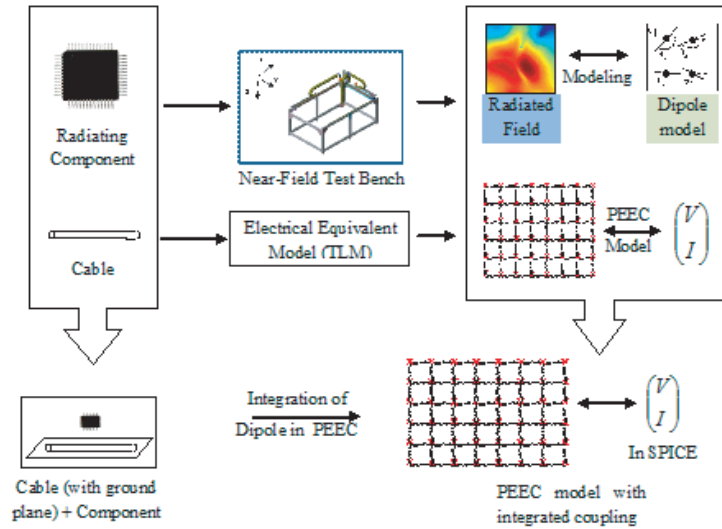


Figure 2: Proposed radiated coupling model.

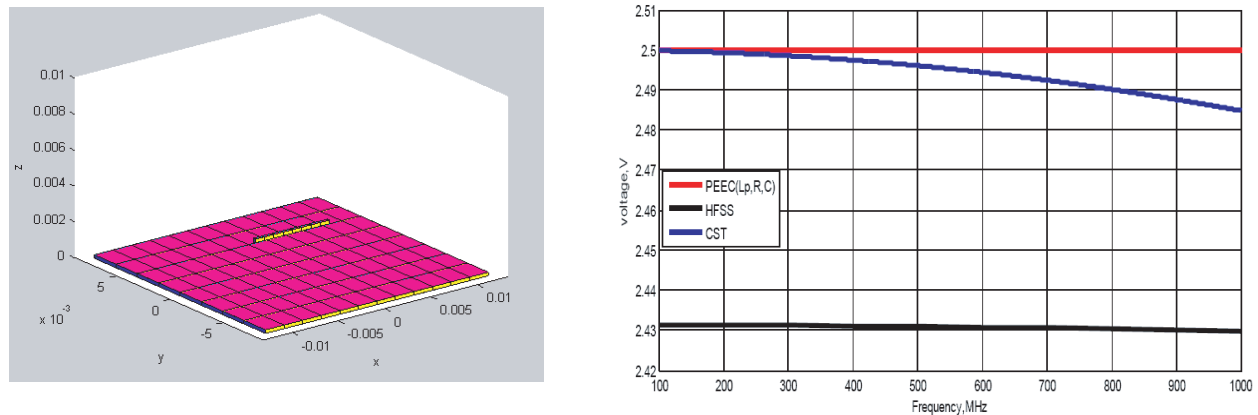


Figure 3: Test setup radiated coupling model & comparison results.

where R is given by $R = |\vec{r} - \vec{r}'|$. The scalar potential term is given by:

$$\Phi(\vec{r}, \omega) = \frac{1}{\epsilon} \int_{v'} G(\vec{r}, \vec{r}') q(\vec{r}', \omega) dv', \quad (4)$$

where v' is the volume of the conductor and q is the charge density at the conductor. If above equations are substituted into an electric field integral equation (EFIE) in the unknown variables \vec{J} and q is obtained as:

$$\vec{E}(\vec{r}, \omega) = j\omega\mu \int_{v'} G(\vec{r}, \vec{r}') \vec{J}(\vec{r}', \omega) dv' - \frac{\nabla}{\epsilon} \int_{v'} G(\vec{r}, \vec{r}') \vec{J}(\vec{r}', \omega) dv', \quad (5)$$

The above equation is then solved by expanding each unknown, \vec{J} and q , into a series of pulse basis functions with unknown amplitude.

4. RESULTS

The test setup is calculated with the HFSS, CST and PEEC method. The configuration is given as follows. The ground plane (length = 28 mm, breadth = 20 mm and thickness = 0.2 mm) and the cable (length = 8 mm, radius = 0.1 mm) is kept above 2 mm height from the ground plane. At the end 221Ω of impedance with lumped RLC port is used for termination at the ends.

5. CONCLUSIONS

From the results of Fig. 3, we observed that the results are in good agreement in FEM, FIT and PEEC models. As the relative error is below 1%, with this agreement in the results prompted us to proceed further with integration of dipole in the PEEC method and compare the results with FEM and FIT methods. Further currently we are working with the implementation of dipole setup with the same setup. with the validation of simulation setup, the same can be done with the measurement setup targeting the industrial oriented problem.

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