Electrical Engineering: An International Journal (EEIJ), Vol. 1, No. 1, June 2014

EFFECTIVE PEEC MODELING OF TRANSMISSION LINES STRUCTURES USING A SELECTIVE MESH APPROACH

A.B Gurulakshmi[1] and Dr. N. Suresh Kumar[2]

[1]Department of Electronics and Communication Engineering,Vickram College of Engineering , Enathi, Tamilnadu
[2] Velammal College of Engineering and Technology, Madurai, Tamilnadu

ABSTRACT

The transmission lines structures are quite common in the system of electromagnetic compatibility (EMC) analysis. The increasing complexities of physical structures make electromagnetic modeling an increasingly tough task, and computational efficiency is desirable. In this paper, a novel selective mesh approach is presented for partial element equivalent circuit (PEEC) modeling where intense coupling parts are meshed while the remaining parts are eliminated. With the proposed approach, the meshed ground plane is dependent on the length and height of the above transmission lines. Relevant compact formulae for determining mesh boundaries are deduced, and a procedure of general mesh generation is also given. A numerical example is presented, and a validation check is accomplished, showing that the approach leads to a significant reduction in unknowns and thus computation time and consumed memories, while preserving the sufficient precision. This approach is especially useful for modeling the electromagnetic coupling of transmission lines and reference ground, and it may also be beneficial for other equivalent circuit modeling techniques.

KEYWORDS

Transmission Lines, PEEC Method, selective mesh approach

1. INTRODUCTION

The increasing complexities of physical structures signal features and electromagnetic (EM) environment of modern electronic systems make EM modeling an increasingly tough task. Despite significant advances in EM modeling methodologies, computational efficiency is desirable especially for complex modeling problems. Currently, the partial element equivalent circuit (PEEC) method [1] is one of the promising numerical methods for EM modelling of various engineering problems, e.g., EM compatibility (EMC), EM interference (EMI), and signal integrity (SI) of high-speed digital circuits [2]. The main advantage of PEEC is its ability to provide a circuit interpretation of the electric field integral equation (EFIE) in terms of partial elements, namely resistances, partial inductances and coefficients of potential. It especially has great potentials for mixed electromagnetic-circuit problems because it is ease to integrate the field solver with real circuit elements. Integration of a PEEC model directly into a circuit simulator is computationally expensive for two main facts. One is that a large number of circuit elements are generated for complex structures at high frequencies; and the other is that the circuit matrices based on modified transmission lines [3] are usually dense due to full inductive and capacitive coupling. In order to model/simulate such problems efficiently, developing compact model representation via meshing for the PEEC Model is necessary.

2. OVERVIEW OF PEEC MODELING

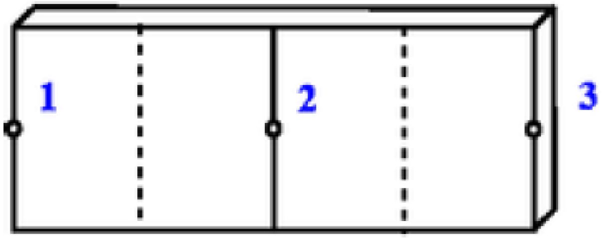
A numerous literature survey on the main numerical methods is carried out and a great attention is addressed to those fulfil the following issues:

- Formulation in both time and frequency domain;
- Full-wave method: the mathematical formulation is based on the complete Maxwell's equations;
- Full-spectrum method: model valid from DC to the maximum frequency determined by the meshing;
- Low computational time.

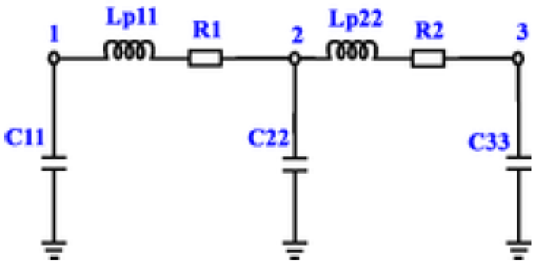
On the basis of these requirements, the Partial Element Equivalent Circuit (PEEC) method is considered the most suitable approach: it is based on the circuital interpretation of the mixed-potential integral and it is characterized by a great versatility in its applications.

2.1. Partial Element Equivalent Circuit Construction

The classical PEEC method is derived from the equation for the total electric field at a point[2].



An orthogonal metal strip with 3 nodes and 2 cells.



The corresponding PEEC circuit.

$$\vec{E}^i(\vec{r},t) = \frac{\vec{J}(\vec{r},t)}{\sigma} + \frac{\partial \vec{A}(\vec{r},t)}{\partial t} + \nabla\phi(\vec{r},t) \quad \text{.... (1)}$$

where $\vec{E}^i$ is an incident electric field, $\vec{J}$ is a current density, $\vec{A}$ is the magnetic vector potential, ϕ is the scalar electric potential, and σ the electrical conductivity all at observation point $\vec{r}$. In the figures on the right, an orthogonal metal strip with 3 nodes and 2 cells, and the corresponding PEEC circuit are shown. By using the definitions of the scalar and vector potentials, the current- and charge-densities are discretized by defining pulse basis functions for the conductors and dielectric materials. Pulse functions are also used for the weighting functions resulting in a Galerkin type solution. By defining a suitable inner product, a weighted volume integral over the cells, the field equation can be interpreted as Kirchhoff's voltage law over a PEEC cell consisting of partial self inductances between the nodes and partial mutual inductances representing the magnetic field coupling in the equivalent circuit. The partial inductances are defined as

$$L_{p_{\alpha\beta}} = \frac{\mu}{4\pi}\frac{1}{a_\alpha a_\beta}\int_{v_\alpha}\int_{v_\beta}\frac{1}{|\vec{r}_\alpha - \vec{r}_\beta|}dv_\alpha dv_\beta \quad \text{....(2)}$$

for volume cell α and β. Then, the coefficients of potentials are computed as

$$P_{ij} = \frac{1}{S_i S_j}\frac{1}{4\pi\epsilon_0}\int_{S_i}\int_{S_j}\frac{1}{|\vec{r}_i - \vec{r}_j|}\,dS_j\,dS_i \quad \text{....(3)}$$

2.2 PEEC model reduction

The rigorous full-wave version of the PEEC method is called (Lp,P,R,t) PEEC, where Lp is partial inductance, P is potential coefficient (inverse of capacitance), R is resistance, and t is delay. If available, reduced model of the full-wave version can be used. For example, if the EIP structure is electrically small, the delay term t can be omitted and the model can be reduced to (Lp,P,R) PEEC model. In addition, if frequency is sufficiently high so that w*Lp >> R, we can omit R term and use approximate (Lp,P) PEEC model. According to various modeling situations, (Lp) and (Lp,R) models are also useful.

2.3 Meshing for the PEEC Model

Meshing is an important issue in accurate and effective PEEC modeling, as other numerical methods [2]. Two kinds of discretizations are constructed in this method. After the initial node placement, surfaces are meshed using quadrilateral elements from which coefficients of potentials are calculated using (1). Depending on the boundaries of the surface mesh, volume cells are created as hexahedral cells from which partial inductances and resistances are calculated using (3) and (4), respectively [5]. It facilitates the partial elements calculation using such quadrilateral and hexahedral elements in the mesh [5, 6].

Figure 1(a) shows the elementary surface and volume discretization in three dimensions, where the numbers 0 » 6 denote the different surfaces, and I ~ VI are the volume cells. Fig. 1(b) presents the node placement of a three dimensional conductor. Three kinds of nodes are set including one inner node as (1), six surface nodes as (2), eight vertex nodes as (3), and 12 edge nodes as (4). Totally, 27 nodes are obtained. With such node placement, 54 surface cells (6x1+8x3+12x2 = 54) are formed as in Fig. 1(c) indicated with different patterns. Fig. 1(d) shows two volume cells, and actually 18 such volumes cells are created in one current orientation by any two adjacent nodes. This results in 54 volumes in total in an ordinary 3-D orthogonal coordinate system [7]. The basic rule of thumb when carrying out the PEEC discretization is to use a fixed number of cells per shortest wavelength λ min (corresponding to the highest frequency of interest) to assure sufficient accuracy. Originally, approximately 10 cells per λmin was

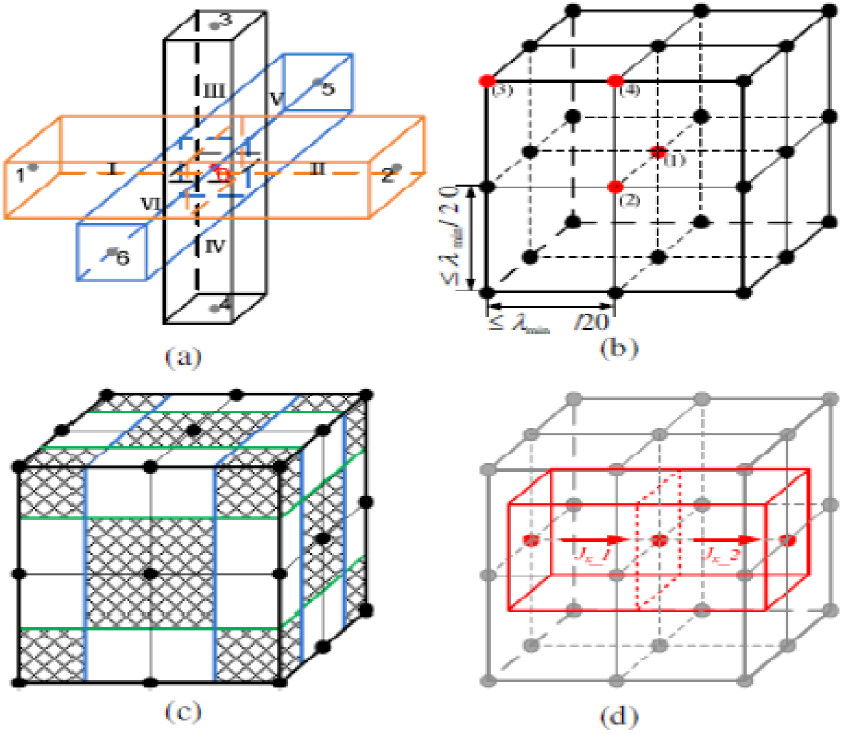


Figure 1. Surface - and volume- mesh of a rectangular structure (a) elementary mesh;(b) node placement; (c) surface cells; (d)volume cells.

3. A NOVEL SELECTIVE MESH APPROACH

3.1 Transmission Lines

If the lengths of traces are in the range of the signal's wavelength, then the user has to consider the effects of transmission lines. The problems that a user must deal with are time delay, reflections, and crosstalk. To get a better understanding of these problems and where and how they arise, it is useful to know what transmission lines are. They are simply the traces on a PCB and depend on the length and the frequency of the signals passing through them. Many different structures of trace routing are possible on a PCB. Two common structures are shown in Figure 2.

On the left, a microstrip structure is illustrated and on the right, a stripline technique. A microstrip has one reference, often a ground plane, and these are separated by a dielectric. A stripline has two references, often multiple ground planes, and are surrounded with the dielectric.

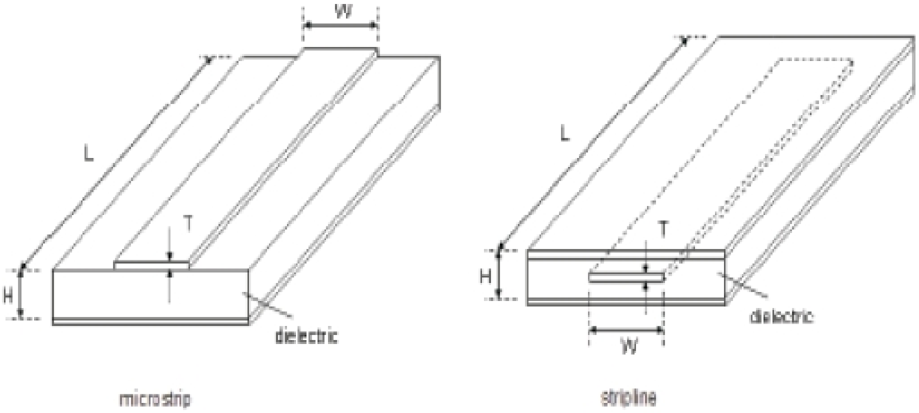
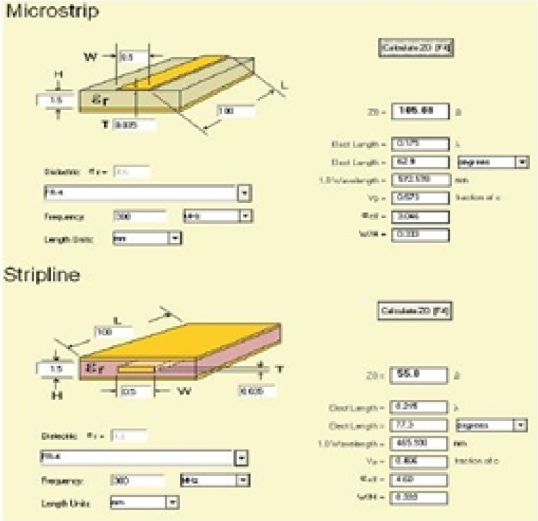


Figure 3. Structure and Dimension of Microstrip and Stripline

The following sections describe some important properties of transmission lines which are significant for PCB design. Many software tools are available to calculate the properties of the several transmission line structures. In this application report, the freeware AppCAD from Agilent is used so that the reader can become familiar with these properties. Figure 4 shows the two structures, microstrip (top) and stripline (bottom). The dimensions, the material, and the frequency are in each case shown on the left. The results that are used in the following sections can be seen on the right. Table 1 defines the symbols used in Figure 3 and Figure 4.



Microstrip

W 0.5
H 1.5
T 0.035
L 100
Dielectric: FR-4
Frequency: 300 MHz
Length Units: mm

Z0 = 105.88 Ω
Elect Length = 0.175 λ
Elect Length = 62.9 degrees
1.0% wavelength = 572.570 mm
Vp = 0.573 fraction of c
εeff = 3.046
W/H = 0.333

Stripline

L 100
H 1.5
W 0.5
T 0.035
Dielectric: FR-4
Frequency: 300 MHz
Length Units: mm

Z0 = 55.8 Ω
Elect Length = 0.215 λ
Elect Length = 77.3 degrees
1.0% wavelength = 465.100 mm
Vp = 0.466 fraction of c
εeff = 4.60
W/H = 0.333

Figure 4. Calculation of Properties of Microstrip and Stripline (AppCAD)

Symbol	Description
H	Height of the dielectric
W	Width of the trace
L	Length of the trace
Z_0	Characteristic Impedance of the trace
λ	Wavelength of the trace at the given frequency
W/H	Ratio between trace width and trace length

Table 1. Description of the Symbols Used in Figures 3 and 4

3.2 A Selective Mesh Approach

The magnetic field H indicates the inductive coupling, while the electric field E represents the capacitive coupling. Since most of coupling energy is concentrated in a limited region, only intense coupling parts are meshed in the proposed selective mesh approach, while the other parts are eliminated. This can reduce the computational time and consumed memory. Here we set mesh boundaries in both sides of a filament, and conventional mesh will be carried out only within the boundaries. The following problem is to quantitatively determine the mesh boundaries.

$$\int_0^{x_0} B(x)dx = k\int_0^{\infty} B(x)dx. \quad \ldots(4)$$

A threshold value k which means the occupation of field within the boundaries over the total field in free space is defined in (4). The threshold value is user-defined which determines the approximation accuracy, and normally a larger value of k results in a better approximation. Numerical validations indicate that a value larger than 0.9 is suitable for most practical problems. It is not difficult to solve the value of x_o in (4), and it is a compact function of the height hand the threshold value k, as shown in (5).

$$x_0 = \tan\left(k\cdot\frac{\pi}{2}\right)\cdot h\,(0 < k < 1). \quad \ldots(5)$$

It is evident in (5) that, with the selective mesh approach, the necessary mesh boundaries of ground plane are dependent on height and the length of the above wires. In some wire-ground structures where the ground conductor is relatively much larger than the mesh region defined by (5), meshing the entire structure in a conventional manner with an identical discretization size is not effective. Figure 5 illustrates a framework of the proposed mesh generation.

1) Count the number of straight wire segments (S_w) and flat planes (S_p). The notation $w^{(i)}_x$, $w^{(j)}_y$, and $w^{(k)}_z$ are used to identify wire segments, and $P^{(l)}_{XY}$, $P^{(m)}_{XZ}$, $P^{(n)}_{YZ}$ to name different planes. The counters i, j, k, l, m, n all start with one. So, $S_w = i + j + k$ and $S_p = l + m + n$..
2) Calculate the distances of wire-plane pair indicated in Table 1.
3) Calculate the mesh boundaries of each non-perpendicular wire- plane pair using (5).
4) Overlapping process. Once the selective mesh surfaces are overlapped, the overlapping subdivisions are merged as

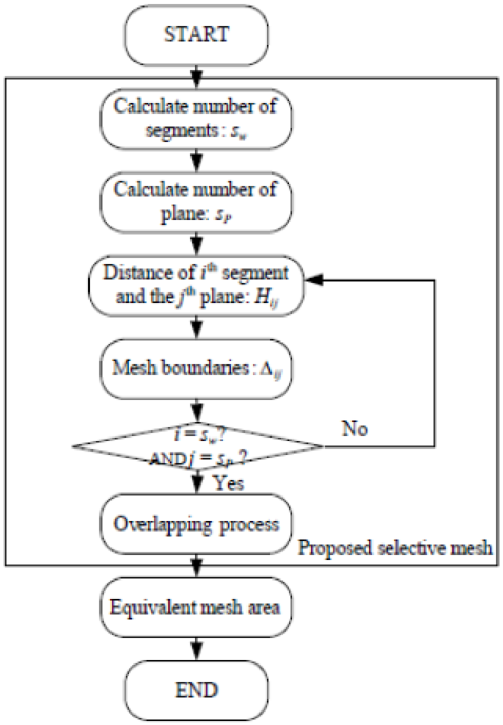


Figure 5. Frame work of the proposed mesh generation.

4. NUMERICAL RESULTS

The configuration of coupled microstrip lines shown in Fig. 7 is typical in printed circuit board (PCB) structures. The common ground provides a possibility of interference due to crosstalk. The two transmission conductors are 50mm long and 3mm apart. They have identical rectangular cross sections with dimensions of 1mm in width and 0.2mm in thickness. A voltage excitation source, V_S (1 volt) consisting of a source resistance R_S (50 ohms) is connected at a terminal S, and another end of the generator conductor is terminated with a 50 ohms resistor. A receptor conductor connects two terminations NE and FE, represented by resistors R_{NE} (50 ohms) and R_{FE} (50 ohms).Excellent agreements are achieved with a suitable threshold value k = 0:95.

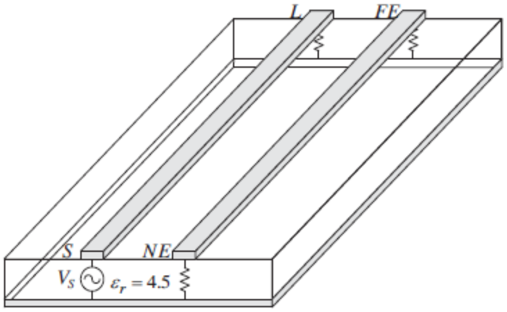


Figure 7. A simulation structure of coupled microstrip lines .

Since our PEEC modelling code at present is mainly based on the quasi-static PEEC model, some difference between measurements and calculations presents at high frequencies.

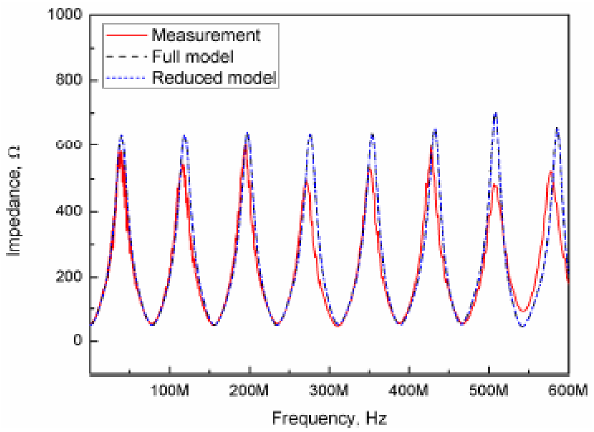


Figure 8. Measurement and nume rical results by full mesh and selective mesh.

	Total Number of		Consumed time (Sec)	
	Nodes	Partial Elements	Element calculation	Circuit solver
Full model	240	54000	170	807.2
Reduced model k=0.95	110	12356	30	28.2

Table 2 Computation consumption of the full model and reduced model

Table 2 shows the numbers of unknowns and the consumed time of the full model and the reduced model. It is evident that the consumed time of the element calculation and circuit solving of the reduced model in this example is only 1/5 and 1/25 of the counterparts of the full model. Numerous practical applications indicate that both the number of unknowns and the consumed time are reduced using the proposed selective mesh approach.

5. CONCLUSION

A selective mesh approach which is consistent with coupled field distribution is proposed for PEEC modeling in this paper. The intense coupling parts are meshed while the remaining parts are eliminated. The resulting meshed region of ground plane is dependent on the length and height of the above conductive path of transmission line. Numerical results show that the mesh approach can greatly reduce the unknowns while preserving the sufficient precision, which follows the reduction of consumed modeling time. This approach especially has potentials for transmission analysis in aspect of system EMC and can be extend to other equivalent circuit modeling techniques.

REFERENCES

[1] Z. F. Song, F. Dai, D. L. Su, S. G. Xie, and F. Duval “ Reduced Peec Modeling Of W ire -Ground St ructures Using A Selective Mesh Approach “, Progress In Electro magnetics Research, Vo l. 123, 355 - 370, 2012

[2] Z. F. Song and D. L. Su “ Model Order Reduction For Peec Modeling Based On Moment Matching ” Progress In Electromagnetics Research, Vol. 114, 285 -299, 2011

[3] Paul, C. R., Introduction to Electromagnetic Compatibility, 2nd edition, John Wiley & Sons, Hoboken, New Jersey, 2006.

[4] Kong, L. and M. Luo, “Co -frequency interference suppression algorithm via maximum signal minus interference level," Progress In Electromagnetics Research, Vol. 104, 183-199, 2010.

[5] Tsai, H.-C., “ Investigation into time- and frequency-domain EMI-induced noise in bistable multivibrator," Progress In Electromagnetics Research, Vol. 100, 327 -349, 2010.

[6] Ding, T.-H., Y.-S. Li, X. Yan, and Y.-Z. Qu, “A new efficient method for calculation and suppression of simultaneous switching noise with the time-domain impedance function for high-speed circuit design," Progress In Electromagnetics Research, Vol. 112, 4-62, 2011.

[7] Paul, C. R., Analysis of Multiconductor Transmission Lines, 2nd edition, Wiley-IEEE Press, New York, 2007.

[8] Roy, A., S. Ghosh, and A. Chakraborty, “Simple crosstalk model of three wires to predict near-end and far-end crosstalk in an EMI/EMC environment to facilitate EMI/ EMC modeling," Progress In Electromagnetics Research B, Vol. 8, 43 -58, 2008.

[9] Kirawanich, P., J. R. Wilson, N. E. Islam, and S. J. Yakura, “Minimizing crosstalks in unshielded twisted-pair cables by using electromagnetic topology techniques," Progress In Electromagnetics Research, Vol. 63, 125-140, 2006.