Removal of Artificial Resonances for Divide and Conquer Analysis using Boundary Element Method

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***Abstract*— This paper presents a mechanism to remove artificial plane resonances using matched termination when analyzing signal channels in a multilayered PCB using a mix of 3D and hybrid boundary element based methodology to model the via transitions and routing areas, respectively.**

Keywords—Boundary element; hybrid solver; plane resonance; matched boundary

I. INTRODUCTION

Divide and conquer methodologies [1] are widespread in modeling signal nets in multilayered PCBs where smaller via transition regions are analyzed by a 3D field solver and the much larger routing areas are analyzed using cascaded transmission line models. Boundary element method (BEM) based analysis is an attractive choice for 3D field solvers as well as sophisticated transmission line analysis, particularly when considering return path discontinuities due to split plane etc., because of its ability to seamlessly generate broadband solution as well as O(N log$N$) cost when used in conjunction with a fast solver. However, in the context of divide and conquer analysis, a big challenge is posed by the artificial reflection that arises from the cropped planes (Fig. 1). Field solutions that are based on the differential form of Maxwell's equations anyway need to make special treatment to handle the boundaries of finite analysis domain, but those are not typically needed for boundary element based analysis as the Green's function itself takes care of the vanishing field values at infinity. For analyzing cropped domains, however BEM needs special treatments to ensure that the radial waves emanating from the vias do not reflect back from the crop boundary discontinuity to avoid artificial signatures corrupting the signal characteristics.

Typical methodologies used in FEM or FDTD analysis to solve this problem, such as absorbing boundary condition (ABC) [2], perfectly matched layer (PML) [3] and lossy padding [4], are usually cumbersome to implement in the context of BEM. Specifically, any solution that requires additional padding typically makes it difficult to ensure that there is no geometrical conflict against existing constituent of the PCB planes, thereby making it less amenable to automation. Moreover, traditional solution based on PML is too complicated and usually an overkill to solve this problem. This paper describes a rather straightforward and intuitive methodology in the context of BEM based 3D [5] and hybrid [6] field solver techniques. Practical examples examining the effectiveness of the methodology in removing artificial resonances and computational overhead are presented.

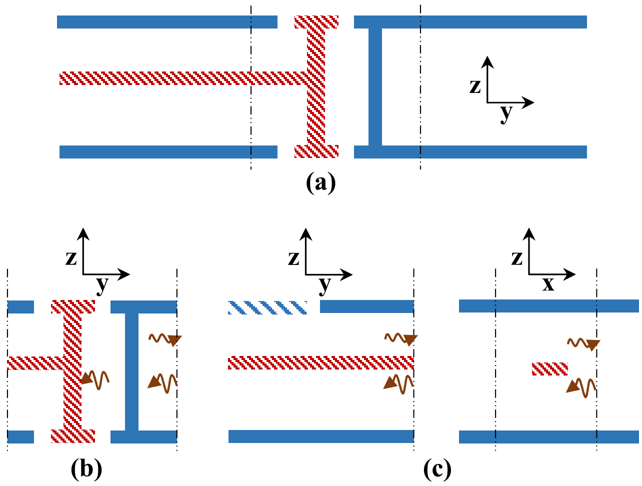


Fig. 1. Mechanism of artificial reflection from cropped edges in PCB planes: (a) Divide and conquer analysis of a typical signal channel in a PCB (b) Reflection in via transition area (c) Side and front view of reflection in transmission line area

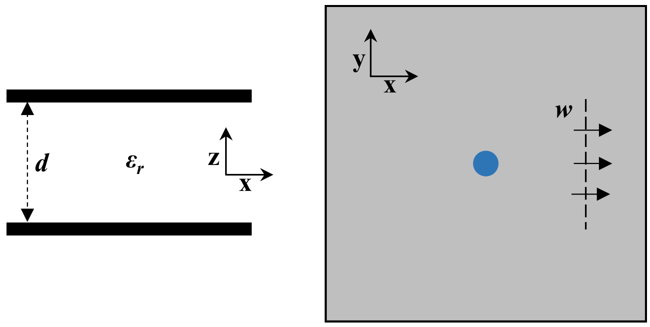
II. GENERAL FORMULATION

The proposed technique is based on the concept of impedance matching at the cropped boundary. Tracking the source of this reflection, when vertical current is drawn through a via structure it emanates an outward wave that propagates through the radial transmission line formed between the PCB planes.

Consider the cavity shown in Fig. 2 with the metal planes separated by a distance d. If a line segment of width w is imagined, the characteristic impedance (Z_0) seen by a wave crossing the segment in a perpendicular fashion is given by:

$$Z_0 = \sqrt{\frac{L}{C}} = \sqrt{\frac{\mu_0}{\varepsilon_0}}\sqrt{\frac{1}{\varepsilon_r}}\frac{d}{w} = \eta_0\sqrt{\frac{1}{\varepsilon_r}}\frac{d}{w} \qquad (1)$$

Without any special boundary treatment – i.e. with a PMC boundary condition the characteristics impedance seen by the wave outside the cavity is given by $\eta_0 \sim 377\Omega$. With a PEC



(a) **(b)**

Fig 2. (a) Side view and (b) top view of a cavity formed by two consecutive PCB planes

termination the termination impedance is 0 and the incident wave is reflected back completely. However, if every boundary segment is terminated with the characteristic impedance given by (1), an approximate matched condition resulting in no reflection can be expected. In reality this is not entirely true, as the plane boundary is not always perpendicular to the wave propagation, but our experiments show it is still effective to remove the false resonances by using this approximate matching mechanism.

III. Matched Termination for 3D Full-wave Solution

A 3D full-wave solution typically relies on all physical structures to be represented in the mesh. The termination described in eq. (1) can be implemented as a sheet object with the application of a specialized impedance boundary condition. For a bulk conductivity σ the AC resistance of a sheet with width w and length d (Fig. 3) can be approximated as $d/(w\sigma\delta)$, where δ is the skin depth for frequency f. From this equation the effective conductivity of the sheet can be computed as a function of f as $\sigma=\pi f \varepsilon_0 \varepsilon_r$ so that a boundary mesh element of width w sees the termination resistance given by (1).

While generating the mesh, the termination material must be placed along all areas that face the exterior of the BEM problem, but do not represent a true external exposure of the original geometry. This is achieved by tracking the composite window boundary through successive crop operations as in (Fig 4). Upon the first crop operation, the absorbing boundary is initialized with the window boundary. In successive crop operations, the boundary is cropped with each new window. The resulting shape touches only the faces where the absorbing boundary is desired. Installation of the absorbing boundary is achieved through a simple post-processing step: mesh elements

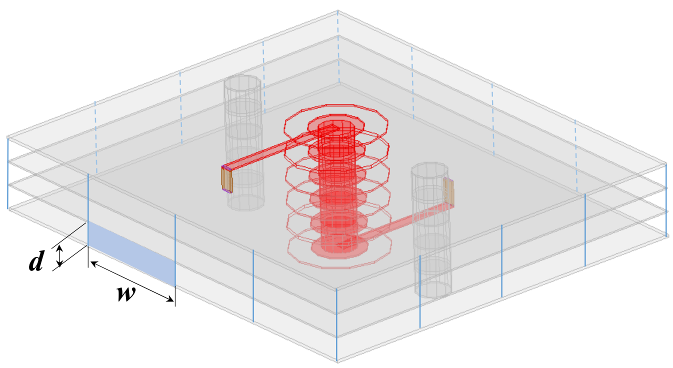


Fig 3. Meshed matching sheet for a 3D via transition model

that represent a dielectric interface and lie along the boundary are replaced with the appropriate absorbing boundary conductor material. The corner case where a dielectric matches

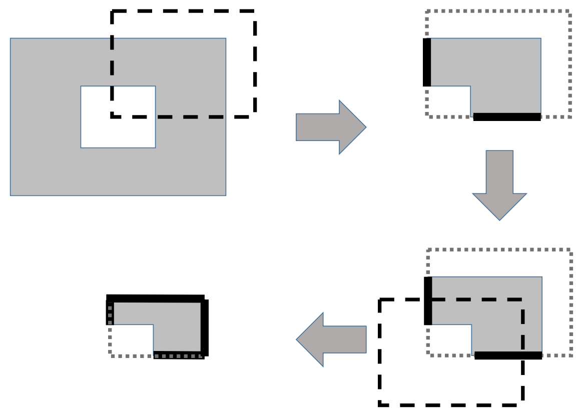


Fig 4. Tracking the absorbing boundary through successive crop operations

the background dielectric is handled by ignoring the redundancy and meshing the boundaries regardless. Later, elements that are found to have the same material on both sides can be discarded in a quick O(N) filtering.

IV. Matched Termination for BEM-Hybrid Solution

Routing regions generated by the divide and conquer methodology can be solved using an ideal or PDN-aware transmission line analysis. When the reference metals belong to the same electric net and are connected near the traces through stitching vias, then the ideal transmission line assumption works extremely well. However, when the reference metals belong to different electric nets or are not connected through vias, the actual results could differ from the ideal one. Therefore, a hybrid solver combining BEM based plane model and transmission lines is best suited for the cropped transmission line regions. Here artificial reflections from the crop boundaries can severely alter the signature across a given frequency band. Application of matched boundary conditions are equally important for this scenario when a hybrid solver is used.

The same termination mechanism used in the previous section applies to the electric field integral equation (EFIE) based BEM solver. Since the waves travel in between planes separated by narrow distances, the variation of the electric field along the vertical axis is negligible making the E-field (nearly) vertical or and the H-field (nearly) horizontal. This simplification leads to efficient implementation of the BEM solver. The solver used in this work [6] uses a vertically consistent mesh thereby creating plane pairs similar to the one shown in Fig. 2. For each mesh element lying at the crop boundary a resistive termination is used as per eq. (1) considering the dielectric constant inside the element pair. Unlike the 3D full-wave solver of Sec. III, no separate termination material is used by the hybrid solver. The crop boundaries are recognized using similar techniques as above and matching characteristic impedances are applied as circuit elements which are stamped conveniently in the system matrix.

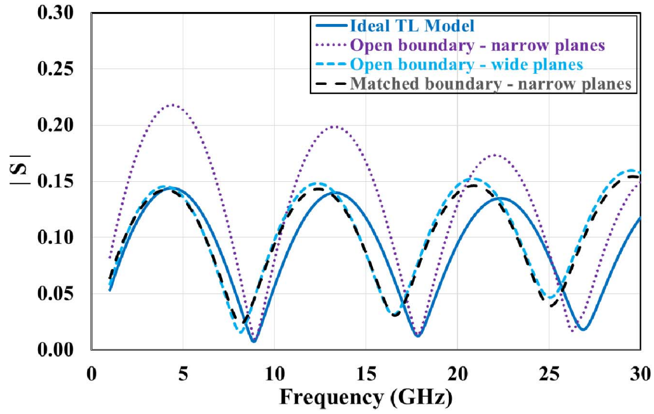


Fig 5. S-parameter for the near-end crosstalk for a pair of coupled traces

V. Numerical Results

Fig. 5 shows the S-parameter for the near-end crosstalk for a pair of coupled signal traces, 2 mils wide each, separated by a center-to-center distance of 4 mils, running symmetrically in between a power net above and a reference net below, under different modeling schemes. The distance of 5.315 mils between the planes is filled with an FR4 material with dielectric constant 2.9 and loss tangent 0.019. Due to the ideal connection assumed between the power and the reference metals, the crosstalk values obtained by the ideal transmission line model are different from the values with the effects of the cropped planes included in the simulation. With a narrow cutout around the traces, the crosstalk is at a significantly higher level compared to the ideal transmission line model due to reflections from the narrow planes. From the hybrid modeling perspective, the actual scenario is represented when relatively wide planes are included with the coupled traces. The crosstalk result with this configuration is different from the results obtained with the narrow planes as shown in the figure. However, the use of wide planes required much more mesh element, roughly proportional to the width of the planes, in the hybrid solver. The matched boundary solution, as can be noticed from Fig. 5, produces similar levels of crosstalk as the wide-plane configuration without using additional mesh elements, which demonstrates the usefulness of the matched boundary configuration in the context of the hybrid solver.

Fig. 6a shows a typical single-ended via transition structure through a multilayered PCB. There is a solder mask layer on top and bottom with dielectric constant 3.3 and loss tangent 0.02. The core (54.05 mils) is filled with material of dielectric constant 4.3 and loss tangent 0.02. A 60 mils long trace with width 5.223 mils is feeding the via-transition on the top and the bottom layer. The anti-pad diameter is 44 mils. Two different models were used with different crop outlines extending away from the stitching via by 75 mils and 112.5 mils respectively. As can be seen from the insertion loss curves in Fig. 6b, without using the matching wall the insertion loss is corrupted by the reflection coming from the plane boundary reflection. This is evident from the fact that when we extend the crop outline from 75 to 112.5 mils the plane resonances move lower in the frequency because of the larger plane size and also diminishes slightly as the edges get farther away from the signal via. On the other hand, the reflections are removed when

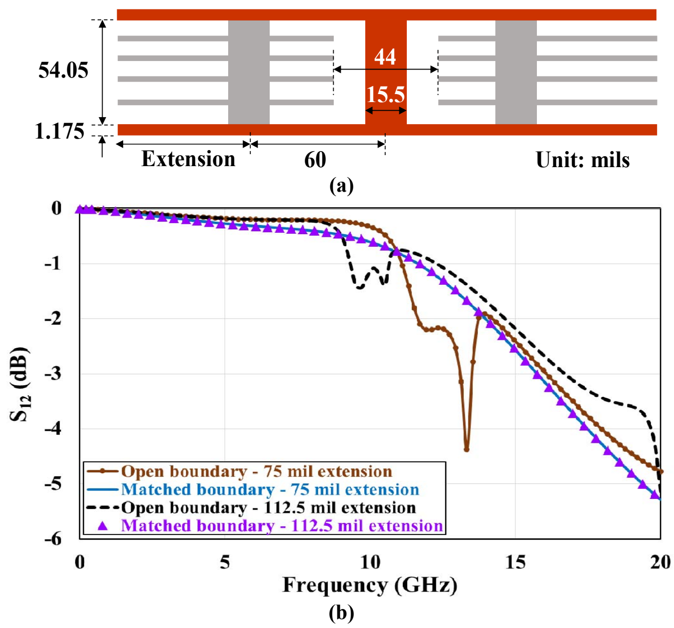


Fig 6. (a) Dimensions of the single ended via transition structure (b) Insertion loss with and without matched boundary using a 3D ful-wave solver

matching wall is used. As expected, moving the matched wall boundary has no impact on the signal characteristics.

Additionally, as the S parameter with matched boundary is smooth, it takes less number of frequency evaluations to converge within an adaptive frequency sweep. This testcase took 313 sec. for the full sweep (converged in 17 frequency points) without the matched wall and took 194 sec. (converged in 10 points) when the proposed matched boundary is used.

VI. Conclusion

This paper presents an intuitive and low cost methodology to reject artificial plane resonance while cropping around a signal net for analysis with boundary element method. Numerical results are presented to show the effectiveness of the proposed methodology when using either a 3D or hybrid boundary element based solution.

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