A Specialized Overlay for Advanced Full-Wave Electromagnetic Simulations within AutoCAD Environment

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Abstract

Our contribution concerns advances in electronics design software, achieved by linking popular Electronic Computer-Aided Design (ECAD) and full-wave electromagnetic (EM) simulations (here, with our in-house conformal Finite-Difference Time-Domain method). We have developed a module that integrates with the EM software and overlays within AutoCAD by accounting for the required wavelength resolution across various materials, while avoiding unnecessarily small mesh elements and simulation time-steps. For example, E-type mesh-snapping planes are set along edges of metallic bodies, while Finite-Difrence Time-Domain (FDTD) elements are deformed and merged into conformal ones, to preserve simulation stability without time-step reduction. Thereby, we have combined the technical merits of ECAD geometry handling, Finite Element Analysis (FEA) flexibility is representing arbitrary shapes, and FDTD outstanding computational efficiency in simulating electrically large circuits over a wide frequency band. The relevance of our contribution extends further beyond the EM project definition and analysis. Namely, the integrated software supports optimization and parameter sweeps, broadening its applicability for engineering applications, which will be illustrated in our talk based on microstrip line example.

Introduction

The integration of ECAD tools with advanced EM simulation methods has become increasingly critical in the design of high-performance electronic systems. Traditional ECAD platforms excel at creating detailed geometric models but often lack the sophisticated capabilities required for robust EM analysis, particularly in cases involving electrically large structures or broadband simulations. To address this gap, our work introduces a novel module that bridges ECAD and full-wave EM simulations, leveraging an in-house conformal FDTD method [1][2]. This module, seamlessly integrated into the AutoCAD [3] environment, enhances the graphical definition of both three-dimensional and planar structures, enabling engineers to directly configure and analyze their designs. Once the geometry is defined, the module automates FDTD meshing and parameter specification, offering a user-friendly interface for assigning materials, ports, boundary conditions, and post-processing settings. The incorporation of conformal FDTD methods within this workflow represents a significant advancement, given the challenges associated with ensuring simulation stability and convergence in time-domain methods [4].

Our methodology is particularly innovative in its approach to meshing, which dynamically balances wavelength resolution across diverse materials while minimizing unnecessary computational overhead. For example, E-type mesh-snapping planes are aligned with metallic edges, and FDTD elements are deformed and merged into conformal shapes to avoid excessively small elements and reduce simulation time-steps without compromising stability. These features combine the precision of FEA in representing arbitrary shapes with the computational efficiency of FDTD in analyzing electrically large circuits [5] across broad frequency ranges. To illustrate the functionality and benefits of this integration, we apply our method to the analysis of a microstrip line which will be described in this paper. The parameters of the microstrip line in this study draw on the work conducted under the iNEMI initiative [6], which ensures the reliability and relevance of our example. We further explore the correlation between material conductivity and signal loss in the microstrip line, demonstrating the module's capability to facilitate detailed optimization and parameter sweeps.

This integration not only enhances EM project definition and analysis but also broadens the scope of applications through its support for optimization and parameterized design sweeps. The resulting workflow provides an efficient, reliable, and versatile solution for engineers addressing complex challenges in modern electronics design.

Overlay Features

The AutoCad overlay transform widely-used mechanical design tools into an advanced platform for EM simulation, design optimization, and also thermal analysis. By integrating EM simulation capabilities directly into the Inventor environment (Fig.1), the overlay eliminates the need for external tools, enabling users to design, simulate, and refine their projects seamlessly within a single interface. It supports the definition of diverse project types, including periodic and axisymmetric (V2D – Vector 2D) structures, leveraging intuitive dialogues to streamline workflows and enhance productivity. The overlay provides straightforward interfaces for configuring electromagnetic simulations. Users can define materials, boundary conditions, ports, post-processing parameters, and excitation profiles with precision. This intuitive approach reduces the learning curve for users while ensuring the setup adheres to best practices for EM analysis. Frequency settings, mesh controls, and other parameters are managed efficiently through user-friendly dialogues, allowing engineers to focus on design objectives rather than software complexities.

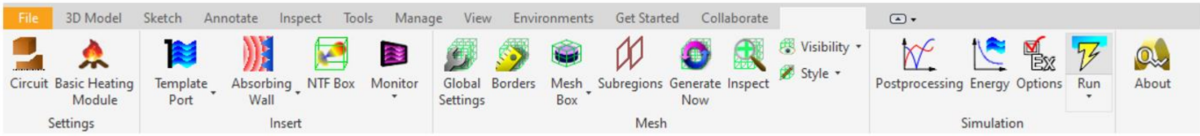

Fig. 1 Overlay ribbon implemented into AutoCAD software.

A standout feature of the overlay is the Automatic Meshing Intelligent Generation Option (AMIGO), which intelligently optimizes the computational mesh for FDTD simulations. AMIGO ensures a consistent wavelength resolution across all media while minimizing the creation of excessively small cells that can inflate computational costs. Users can balance accuracy and efficiency by specifying the minimum number of cells per wavelength and restricting refinements below a threshold. The system dynamically adapts time steps to meet stability criteria, providing accurate results without unnecessary delays. The overlay incorporates mesh-snapping planes to align simulation grids with critical structural elements, improving the fidelity of EM field calculations near edges and interfaces. Snapping planes are classified into weak, soft, hard, and master categories, with priorities assigned to balance accuracy and computational constraints. This approach ensures that critical geometries are accurately modeled while avoiding excessive refinement that could increase simulation times. At below Fig.2 is shown whole design of microstrip line with using of our overlay

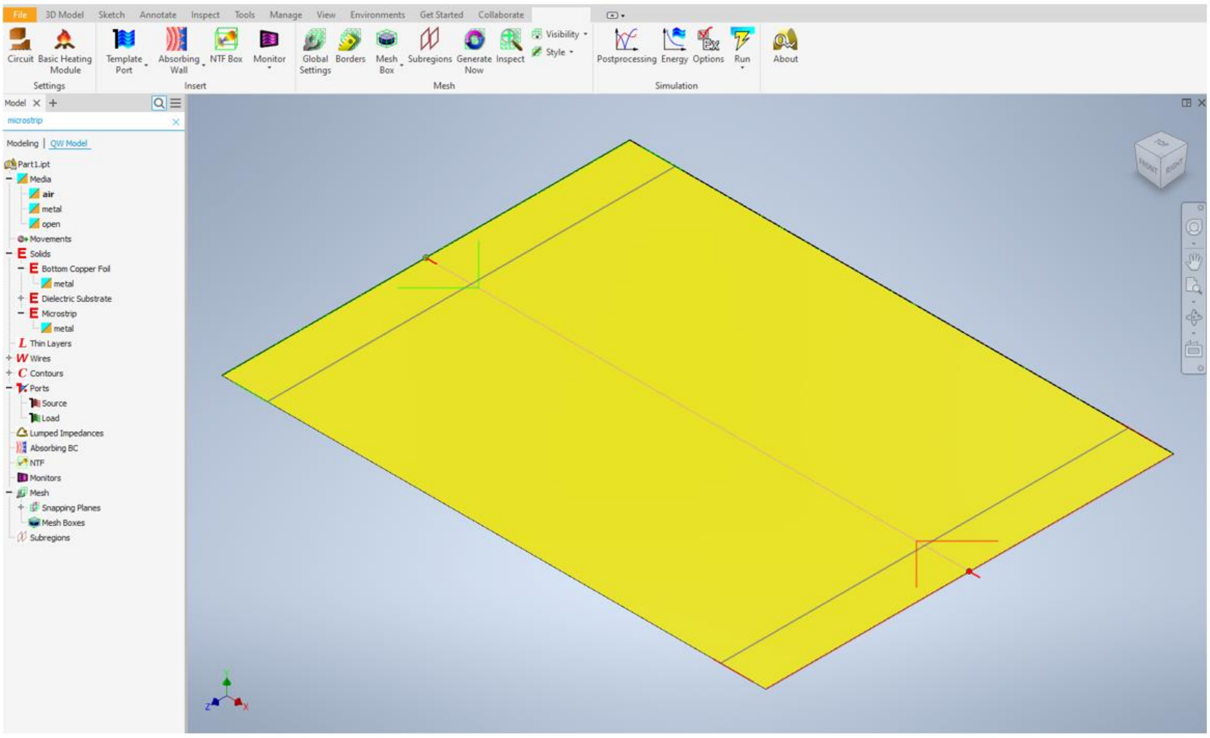

Fig. 2 Overlay View with Object Tree for example of microstrip line.

The Heating Module [7], integrated into the overlay, extends its capabilities to include thermal analysis and heating simulations. This module dynamically modifies material properties based on dissipated energy, enabling simulations of real-world heating effects. It supports modeling of rotating and moving objects along arbitrary trajectories, thermal analysis of complex geometries, and non-linear heat transfer problems. By coupling electromagnetic and thermal effects, the module provides an accurate representation of processes such as energy dissipation and heat distribution in various materials.

The overlay supports optimization and parameter sweeps through integration with EM Optimiser and a Grid Search regime [8]. These tools allow users to explore a wide range of design configurations, identify optimal solutions, and analyze sensitivity to mechanical tolerances. With flexible parameter grids and visualization options, engineers can efficiently refine their designs and identify performance trade-offs. The overlay's export to special file format functionality facilitates the transfer of project data to standalone EM simulators. This integration enables advanced post-processing and further simulations without the need for redundant setup, ensuring a smooth workflow from design to analysis.

Microstrip Line example

Microstrip transmission line technology is a widely adopted method for characterizing copper foil conductivity in printed circuit boards (PCBs), offering a practical, reliable, and cost-effective solution for signal integrity analysis. As part of a Design of Experiments (DOE) methodology, signal integrity coupons were fabricated using microstrip technology etched onto a two-layer PCB, chosen for its reduced fabrication turnaround time, low cost, ease of preparation, and simplified testing. This procedure was done as a part of work in iNEMI initiative. Based on this work we prepare a model in our overlay shown on below Fig.3.

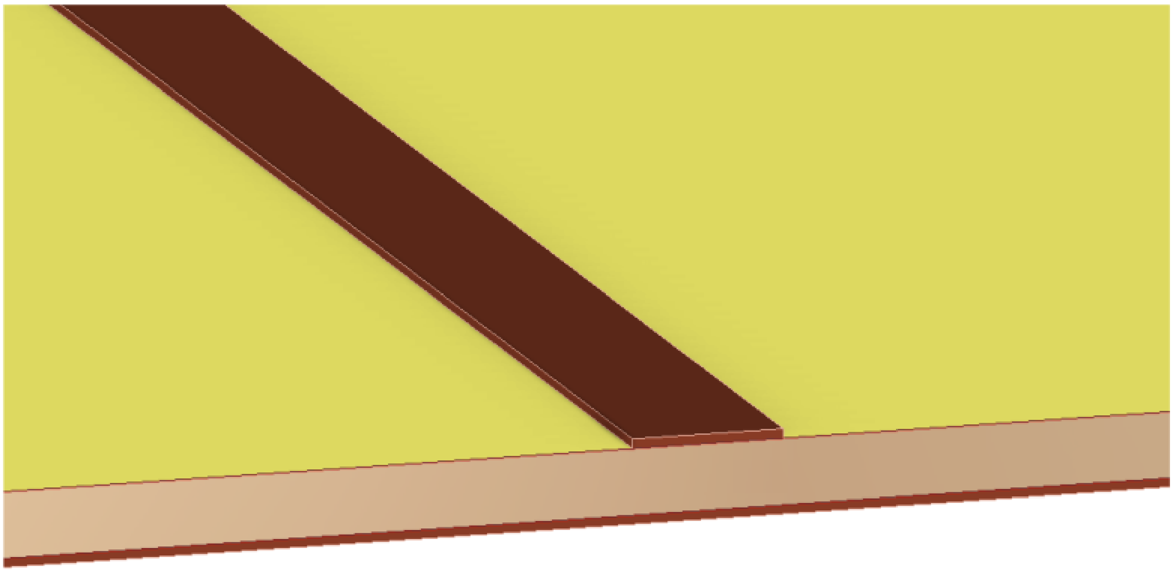

Fig. 3 Zoom on metalization in 3D model made in our overlay.

The substrate material, is an extremely low-loss, halogen-free material provided by a single supplier to ensure consistent performance. Such experiment was done as a part of iNEMI project and gives a motivation to chose this particular substrate [9][10]. The microstrip design parameters as shown at Fig.4 included a trace width W of 0.0115 inches, a substrate thickness H of 0.005 inches, and copper weight T of ½ oz with additional plating. The structure was built on a 18-inch by 24-inch panel with 2116 56% RC construction, and the dielectric constant (Dk) and dissipation factor (Df) of the substrate were 3.33 and 0.0018, respectively. To show work of the overlay we change a size of model to avoid very high density of cells. So we change panel size into 3 inch by 4 inch. This approach doesn't affect results but significantly short the time of EM simulations.

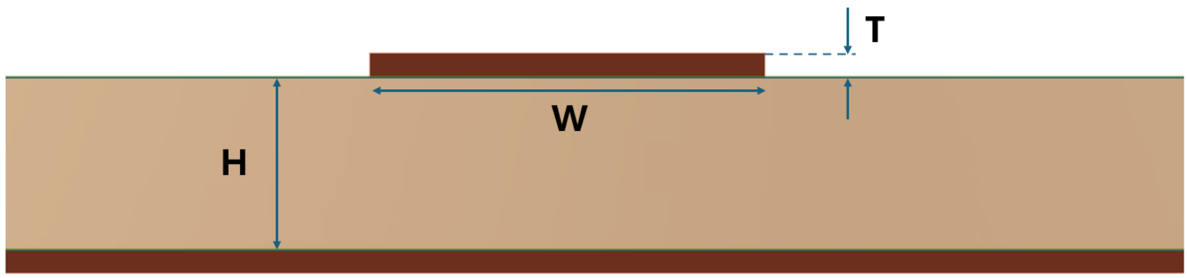

Fig. 4 Microstrip design parameters of the model created in AutoCad using also our overlay

To accurately model the microstrip, a detailed 3D CAD design was created, incorporating an airbox of 0.02 inch height above the microstrip and enclosing the entire structure in a metal box where the bottom metallization of the microstrip formed one wall. The design was excited with a transverse electromagnetic (TEM) field across a frequency range of 0 to 50 GHz. To improve computational accuracy, a high-density mesh box was introduced at the excitation point, featuring cell sizes of 0.001 inches in the X direction and 0.0001 inches in the Y and Z directions. This dense meshing ensured a high-resolution representation of the source and quasistatic field template calculations. Outside the mesh box, bigger mesh sizes of 0.1 inches (X), 0.001 inches (Y), and 0.01 inches (Z) were used to optimize computational efficiency, with the overall simulation requiring 3328 MB of RAM. Distribution of cells are shown at Fig.5. It is visible that used meshbox focuses a cells near excitation point allows to precise simulation of quasistatic template. Postprocessing focused on calculating S-parameters over the specified frequency range with a resolution of 0.01 GHz, providing comprehensive insights into the microstrip's electromagnetic performance. This approach demonstrated the effectiveness of microstrip-based signal integrity coupons for DOE applications, offering precise characterization of copper foil conductivity and establishing a foundation for designing high-performance, low-loss PCBs suitable for advanced applications.

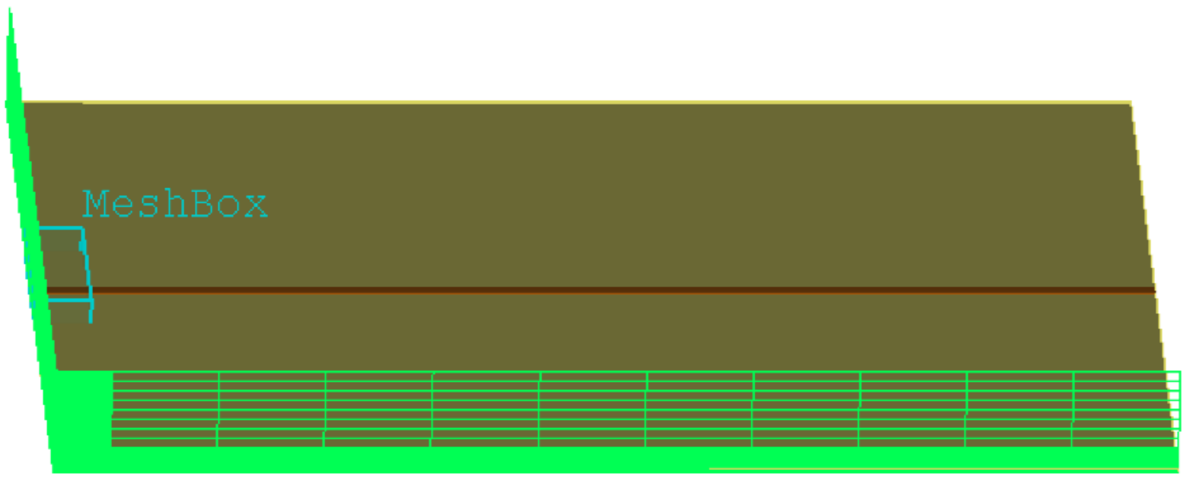

Fig. 5 Distribution of cells on prepared microstrip line model.

Results

The simulation study aimed to explore the effects of varying the metal conductivity within a controlled environment using our AutoCAD overlay. The metal, defined as the entire box enclosing the system and the microstrip line, underwent a systematic Grid Search optimization process. We implemented a Grid Search Regime to evaluate the influence of metal conductivity on system behavior. The conductivity (σ) was varied logarithmically from 1×10^5 S/m to 5×10^7 S/m, using a step size corresponding to 10^{n+1}, where n represents the simulation step index starting from 0. This approach enabled a comprehensive assessment of a wide range of conductivity values while maintaining computational efficiency. It is important to note that the substrate's conductivity was held constant throughout the simulations. While including frequency-dependent variations in substrate conductivity could provide additional insights, such changes would necessitate a significantly larger number of simulations, thereby extending the total computational time. As this study primarily focuses on the impact of metal conductivity, such substrate variations were excluded.

The complete Grid Search process, consisting of simulations across all specified conductivity values, was conducted on an AMD Ryzen Threadripper 2950X 16-Core Processor running at 3750 MHz. The total computation time for the Grid Search was 21 minutes 28 seconds. This performance highlights the efficiency of the selected computational approach, enabling an extensive parameter sweep within a practical timeframe. While this chapter does not delve into detailed results, it establishes the methodological framework and computational feasibility underpinning this study. The outcomes of this Grid Search provide valuable insights into the relationship between metal conductivity and insertion loss as shown below on Fig.6.

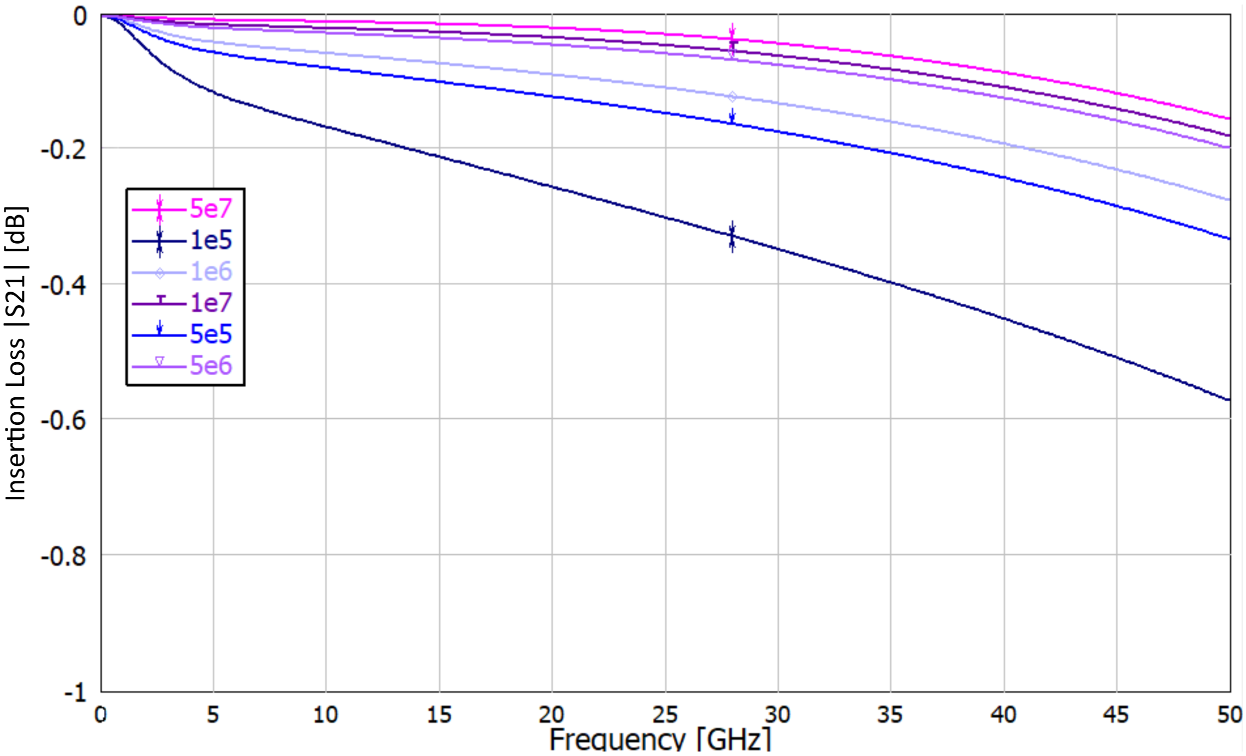

Fig. 6 Increase in Insertion Loss |S21| versus frequency for different metal conductivities.

In future work, comparisons will be made between the results obtained from simulations in this study and corresponding experimental measurements. To illustrate this, we analyzed the insertion loss at 28 GHz as an example of state-of-the-art research demonstrating the relationship between insertion loss and conductivity (Fig. 7). The findings show a drastic increase in loss as conductivity decreases, following a logarithmic trend. Specifically, the sensitivity to changes in conductivity is significantly higher in the lower conductivity range, particularly at 1e5 S/m. This highlights the critical importance of accurate measurements in regions of higher conductivity for improved correlation with simulation data.

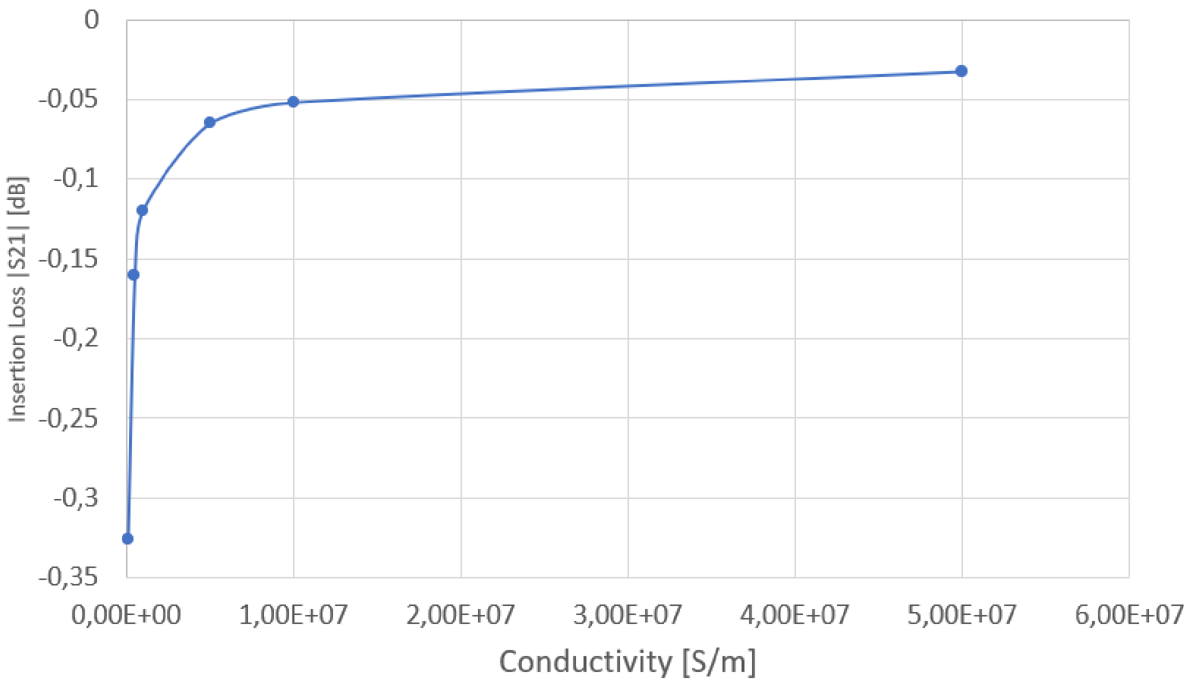

Fig. 7 Insertion Loss versus metal conductivity at 28 GHz.

Conclusions

This work has demonstrated the effective integration of ECAD tools with advanced EM simulation methods, leveraging a novel AutoCAD overlay module. By incorporating conformal FDTD techniques, the module enables precise and efficient analysis of complex electronic designs like shown as the example in this study a microstrip line The seamless integration with AutoCAD allows for intuitive geometry creation, automated meshing, and the definition of simulation parameters, significantly enhancing the user experience and reducing the learning curve. Key innovations include the AMIGO, which optimizes computational resources while maintaining simulation accuracy, and advanced meshing strategies such as mesh-snapping planes, mesh boxes and adaptive time-step controls. These features provide a balanced approach to resolving critical structural elements while minimizing unnecessary computational overhead. The application of the module to a microstrip transmission line exemplifies its capabilities, including the precise characterization of signal integrity and the exploration of conductivity effects through a systematic grid search optimization process. The study underscores the module's efficiency, with a complete parameter sweep conducted within a practical timeframe, and highlights its potential for broader use in designing high-performance, low-loss PCBs. By coupling EM and thermal analysis, the module also supports multi-physics simulations, expanding its scope to include heating effects and complex thermal processes which is a part of future work. In this time main goal is to correlate a simulations results with a measurements of prepared microstrip lines within iNEMI project.

Acknowledgments

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