ELECTROMAGNETIC SIMULATOR INTERFACING TO A GENERAL CAD FRAMEWORK: AUTOMATIC, ELECTROMAGNETIC-BASED MESH GENERATION

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Abstract

An electromagnetic simulator has been interfaced through a custom-meshing program to a general CAD framework. Standard information within the CAD framework (netlist information, location in layout and maximum simulation frequency) is all that is needed to automatically generate a surface mesh (consisting of triangles and rectangles) for the circuit through a systematic multi-level procedure. Additionally, the unique physics of particular elements can be easily incorporated into the mesh generation, thus ensuring accurate simulation.

Introduction

Node-based analytical expressions are the basis for most electrical models used in high frequency circuit designs. This is adequate for previously explored structures and discontinuities; however, many designs exist where more accurate and flexible models are required. Electromagnetic analysis is being utilized to obtain many of these electrical models. For example, novel structures require electromagnetic analysis. Additionally, the process of circuit compaction will often violate implied assumptions of many analytical models. For these and many other designs, electromagnetic analysis is now being used to generate electrical models.

Given that electromagnetic simulation is a part of the design methodology for many circuits, one of the main drawbacks to its utility is the time required to obtain the model. This time cost resides in three categories: software learning curve, problem setup, and simulation time.

Although CAD frameworks and electromagnetic simulation tools are becoming more popular, there are very few electromagnetic simulation tools integrated transparently into CAD frameworks. By completely integrating an electromagnetic simulator into a CAD framework, the learning curve and problem setup time of performing a simulation are virtually eliminated. The design entry is made transparent by utilizing the standard schematic elements native to the other simulation tools used in the framework. In this way the ease of use of parameterized analytical models is transferred to the electromagnetic simulator. Additionally, by using a standard simulation interface used in the framework for the other simulation tools, there is no additional learning curve. Finally, simulation time is minimized by utilizing a fast electromagnetic simulation engine.

This integration utilizes a systematic multi-level procedure, converting elements into groups of primitive geometric shapes. Each of these geometric shapes are further converted into a local surface mesh. Finally, each local surface mesh is attached to the adjacent surface meshes to form the final mesh for the electromagnetic analysis. One of the major advantages to this approach is that the physics of a particular element can be implicitly captured in the electromagnetic mesh.

Presented in this paper are a summary of the CAD system, basic characteristics of the CAD framework, the methodology of the conversion from schematic (netlist) to electromagnetic mesh, and examples.

CAD System Summary

Current CAD interfaces include schematic and layout representations, and are easy to use and customize. They transparently invoke various simulation tools, assemble the required simulation data, and often redirect the outputs to standard graphics programs.

The CAD framework used is EEsof's Project Design Environment, the nodal simulator used for syntax is Libra, and the first electromagnetic engine integrated in this manner is based on the MIMICAD PMESH simulator [1-5] from the University of Colorado in Boulder.

CAD Framework

The human interface to this CAD framework utilizes MOTIF-style windows and dialog boxes. Common operations are grouped into a fixed palette in iconic form for quick operation. Multiple element libraries are supported both via list and also a scrolling iconic palette for easy selection and placement. Since schematic and layout have a close association in high frequency design, a common visual representation is provided for both representations. One can even have both representations on the screen simultaneously.

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A unique feature in the EEsof Project Design Environment (PDE) system is the common representation of both schematic and layout in a single database. This mechanism allows the two views to be properly tracked. Coordination between the schematic and layout is handled through the Design Synchronization Engine (DSE). When active, DSE ensures that the schematic and layout representations coincide. There are many advantages to DSE. One of the more important ones is allowing the user to enter a design in either the schematic or the layout and have the other representation properly generated. Another advantage is that the nodal-based simulation has a netlist which reflects the physical design rather than just a symbolic view. Synchronization of these two databases is key to the operation of the mesh generation program.

The simulation framework consists of PDE and a number of EEsof simulators and programs that communicate with each other. A standard message protocol has been established to minimize the complications associated with integrating many tools. This mechanism is very robust, allowing tools to communicate across multiple homogeneous or heterogeneous platforms. This feature allows one to take advantage of a fast machine for simulation while using a slower machine for design entry.

Interfacing to the mesh generation program is accomplished by the PDE which generates a "netlist" of the design and sending it to the mesh program. (This is not a true netlist, but rather a network description delivered by standard protocol.) Each item in the schematic has a protocol line associated with it. The syntax for an element such as an MLIN or MSUB includes its name, a unique tag, parameters and parameter values. Appended to each element description are its location and orientation for external tools such as the mesh program which require this spatial information.

Mesh Generation Program

When an electromagnetic simulation of the design is requested, the entire netlist is sent to the custom mesh generation program through the standard message exchange protocol. This netlist is transformed into geometric shapes, then into an electromagnetic mesh as described in the next section.

The node-based simulation assumes that there is a microstrip mode established at the ports, so de-embedding arms are added automatically. Material definitions and simulation frequencies are also defined within the netlist.

Simulation Engine

The electromagnetic simulation engine utilized is based on PMESH. PMESH was originally developed at the University of Colorado in Boulder in conjunction with the MIMICAD center. This electromagnetic engine is a full-wave spatial-domain mixed-potential integral equation simulator, utilizing roof-top basis functions on a rectangular and triangular mixed mesh [1-5]. A mesh data structure consists of cells, sides and points, with a requirement that adjacent cells have a common side. Modifications have been made to make the de-embedding more robust, obtain 50-ohm S-parameters, account for images for large cells, and allow shorts to ground.

Mesh Generation Methodology

The process of taking a circuit from a "netlist" to a surface mesh is a multi-phase conversion. There are four stages to this process: element, primitive geometry, local surface mesh, and finally global surface mesh. Each supported element is transformed into primitive geometric shapes. Each shape is further converted into a local surface mesh. Finally, each of the local surface mesh regions are resolved into a global mesh by identifying and resolving the zonal boundaries between adjacent local surface mesh areas. Although applied to a different industry and computational requirement, a similar outline was presented by Luh [6] to construct analysis mesh from a surface mesh for primitive geometric shapes.

From the augmented netlist, primitive geometric shapes can be generated for each element. Currently, the geometric shapes include rectangles, triangles and trapezoids. Some elements like a microstrip line have a single primitive geometric shape (rectangle). Other elements require a number of geometric shapes to create the element. For example, an arbitrary microstrip bend requires a number of triangles. In preparation for the final phase, nodes are identified as zonal boundaries for interfacing local surface mesh of adjacent elements.

Each of the geometrical shapes are processed into a local surface mesh. By noting the maximum frequency and the electrical properties of the material, a maximum cell dimension is obtained. Each shape has routines that handle the generation of the local mesh for that shape. Rectangular geometric shapes are decomposed into a mesh of rectangular cells. Triangles, trapezoids and other shapes require more advanced techniques. One example is a variation of the advancing front technique [7]. The boundary of the shape is discretized based on the maximum length. The mesh front is initialized by the discretized boundary. This boundary is used to generate cells, which reduces the size of the remaining shape. This procedure is iterative which often results in recursive functions.

Finally, zonal boundaries are examined between each attached local surface mesh. These are interfaced so that the mesh requirements are met throughout the circuit [6,8]. The circuit nodes in the netlist are used to define these zonal boundaries. Examples of the zonal boundary interfacing phase can be seen with step discontinuities and microstrip slit elements.

Ease of use is only one of many benefits to the complete integration of an electromagnetic simulator into a CAD framework. One benefit is the ability to capture specific electromagnetic characteristics of an element by properly selecting the geometric shapes used to represent that element.

A coupled microstrip line with a wide spacing experiences mild current skewing so one cell wide is adequate to capture the electrical behavior (Figure 1a). However, if the spacing is small, the current will crowd the inside of the line [9]. Knowing this, an alternate set of primitive geometric shapes is utilized in the conversion of coupled microstrip element (Figure 1b).

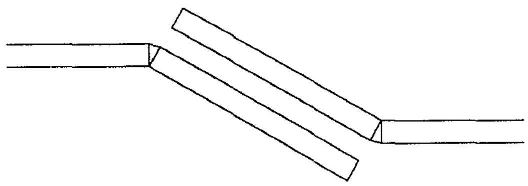

Figure 1a. Primitive geometric shapes for a lightly coupled microstrip circuit.

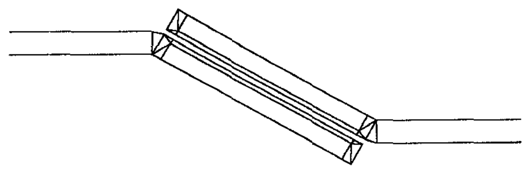

Figure 1b. Primitive geometric shapes for a tightly coupled microstrip circuit.

Examples

Two examples illustrate the integration of an electromagnetic simulation tool with this CAD framework: a lowpass filter (LPF) and a bandpass filter (BPF)

LPF Example

A 10 GHz lowpass filter [10] is entered into the CAD framework (Figure 2a). Both layout and schematic are available in the database. When an electromagnetic simulation is requested, the augmented netlist is generated and sent to the custom meshing program. The electromagnetic mesh is automatically generated (Figure 2b) and simulated (Figure 2c). This structure is converted into 13 geometric shapes (all rectangular), and two zonal boundaries requiring modifications exist (where the triangles are located). The simulation has 105 unknowns and takes 107 seconds per frequency on a Sparcstation IPC with 24 MB RAM.

Since the electromagnetic modeling analyzes the layout it doesn't matter if you model this structure with microstrip cross junction and open end microstrip lines or straight through microstrip lines with step discontinuities. In both cases the layout is the same, and although the generated mesh is slightly different the electromagnetic simulation results are identical.

BPF Example

A "35 GHz bandpass filter" [11] is entered into the CAD framework (Figure 3a). For this circuit the proper simulation of tightly coupled lines and mitered bends are critical. An electromagnetic simulation is requested, then the mesh is generated (Figure 3b) and simulated (Figure 3c). The simulation has 108 unknowns and takes 188 seconds per frequency on a Sparcstation IPC with 24 MB RAM.

Two aspects of this simulation are significant: arbitrary cell placement and mesh generation based on known physics. Notice that arbitrary angles can be used within the structure. This is due to the flexibility of the spatial domain simulation engine. Current crowding on the inside edge of coupled lines is a well-known phenomenon of the microstrip coupled line structure. The mesh is constructed to model this current crowding with the fewest number of unknowns. Notice the mesh on the two coupled lines sections and on the outside lines of the three coupled line section, but no crowding on the center line of the three coupled line element. The simulation, with this discretization, is directed to capture the critical physics of the circuit without burdening the computation with unnecessary unknowns.

Summary

A transparent connection between an electromagnetic simulator and a CAD system with a unified schematic/ layout database has been achieved. Elements are interpreted as a collection of geometrical shapes. Each geometric shape is processed into a local surface mesh. Finally, the zonal boundaries between local surface meshes are resolved. Elements that are understood by the custom mesh generation program include microstrip curves, radial stubs, coupled microstrip lines among others. Two examples have been given. For these examples, the time required to obtain an electrical model has been reduced to the electromagnetic simulation time: the learning curve is that of the CAD framework and the meshing time is negligible.

References

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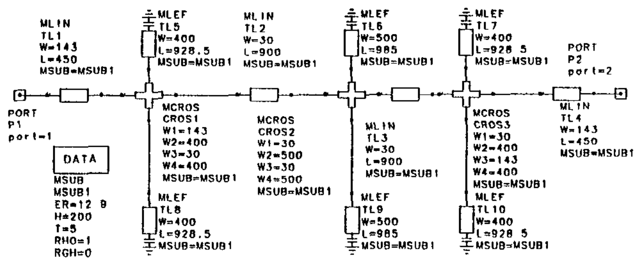

Figure 2a. Schematic of 10 GHz lowpass filter (LPF).

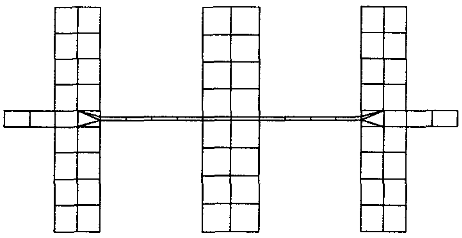

Figure 2b. Mesh used for electromagnetic simulation of LPF.

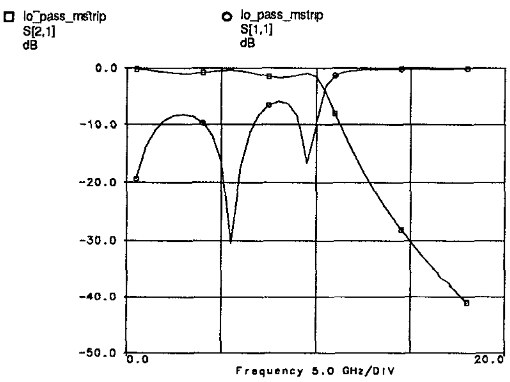

Figure 2c. Electromagnetic simulation results of LPF.

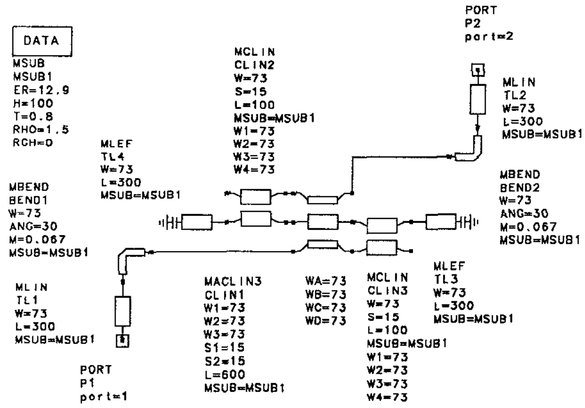

Figure 3a. Schematic of "35 GHz" bandpass filter (BPF).

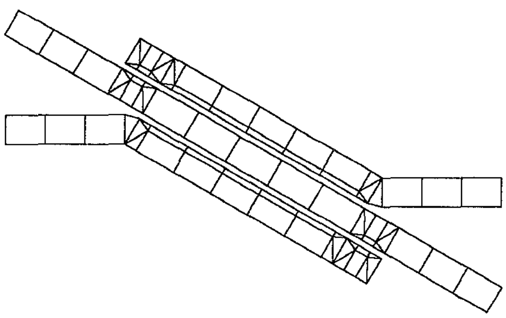

Figure 3b. Mesh used for electromagnetic simulation of BPF.

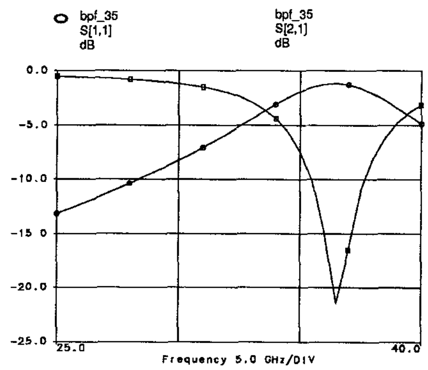

Figure 3c. Electromagnetic simulation results of BPF.