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Full-Wave Electromagnetic Simulation of PWB Structures

Paul Svasta, Norocel-Dragos Codreanu, Ciprian Ionescu and Virgil Golumbeanu
"POLITEHNICA" University of Bucharest
Center of Technological Electronics and Interconnection Techniques (CETTI)
Bucharest, Romania

Abstract
Because high performance products are limited in speed by packaging and interconnections, signal integrity analysis and PWB simulation become nowadays very pressing and key issues. Taking into account these aspects, the discontinuities of signal traces have also a more and more important contribution. For instance, in the past the biggest problems regarding vias/via pads were only solderability and manufacturability. Today a via is understood also as an electrical discontinuity and has to be properly designed and used.

The paper intends to present investigations realized in the labs of Center of Technological Electronics and Interconnection Techniques (CETTI) from Bucharest, Romania, and focused on the influence of discontinuities and parts of metallic interconnection networks on high-speed/high-frequency signals propagation. A computer modeling was made and Spice models for a good compatibility with circuit simulators were obtained. S-, Y-, Z- parameters of different kind of structures were calculated, too. The evaluation was realized by a modern MOM (Method of Moments) electromagnetic simulation technique.[1] At the end, a library of models for different discontinuities was generated.

Introduction
Electromagnetic simulation of printed wiring boards (printed circuit boards) is today an essential CAD activity due to the advantages that it is possible to evaluate before manufacturing the metallic interconnection structure, to find the best ways to develop the boards, to solve on-board signals transmission problems and to optimize the time-to-market. Taking into account the topics from above, the paper presents the work done in Center of Technological Electronics and Interconnection Techniques regarding the influence of natural or forced PWB discontinuities on some specific performance applications. Field and current distributions of simulated configurations are accessible for ulterior analysis. For all discontinuities, RLCG circuit in SPICE format and S-, Y-, Z-parameters are obtained.[4] Using "Modua", a graphic display software and nodal circuit simulator, part of Zeland modeling and simulation environment, various results, for a better understanding of discontinuities, are obtained. With "Curview" software the authors can offer also 3D views of discretized configurations, high-quality field and current distributions on structures.[1, 2, 3] At the end of the research a library of models was generated. The library is useful for future activities in order to provide a large quantity of important data for printed circuits design and fabrication.

Modeling and Simulation
For proper PWB items generation, an electromagnetic computer modeling and a full-wave simulation were realized to find the adequate geometries and to obtain the necessary parameters. The computer used for these activities was a compatible IBM PC/AT Pentium III/500MHz with 512 MB RAM memory. A structure for electromagnetic simulation can be prepared either through a Gerber–CIF conversion (Figure 1) or by creation from scratch, using "MGrid", the layout editor for construction the geometry.

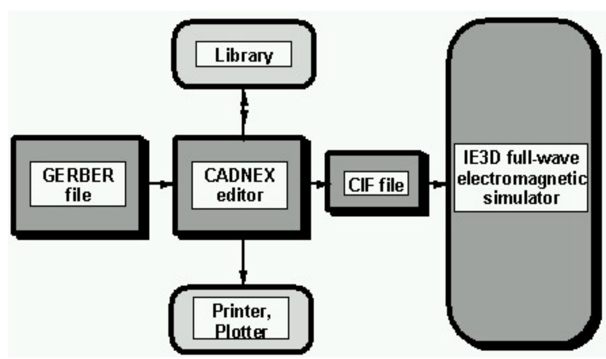


Figure 1 - Gerber → CIF conversion

In the figure the path between well-known Gerber files (produced by all PWB CAD tools) and the special CIF format (able to be imported for simulation) is presented. The new configurations obtained in IE3D Zeland software system are layered structures but an important benefit is that it is possible to build also spatial entities (vias, solder balls, wire bonds) and to study them from the all electromagnetic viewpoints mentioned above.

In Figure 2 a 3D view of a specific transferred PWB layout is presented. One can observe that the entire structure was transformed into a finite elements structure, which can be studied at different frequencies of interest. In Figure 3 some entities destined for electromagnetic simulation are offered. These items can be cut from the layout or can be built as independent objects, in order to satisfy the geometrical and electrical conditions. The mesh is automatically generated during the gridding phase but the designer can create also manually, in some particular areas, special configurations of finite elements.

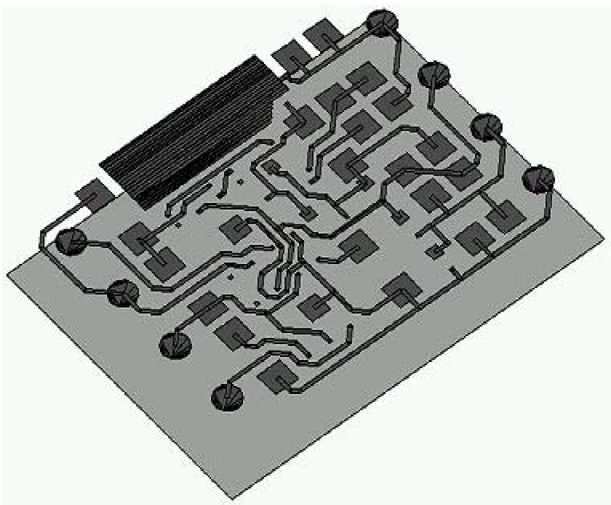


Figure 2 - 3D View of a Transferred PWB Layout

In order to simulate PWB structures the electromagnetic simulator was used, which actually combines two types of simulators. For planar (2D) structures or three dimensional (3D) structures (in a layerstack arrangement) the simulation, based on the Method of Moments, offers the best results. A very powerful feature of this simulator is that we can combine the results and can extract a lumped parameter model of the structure, based on the results obtained.

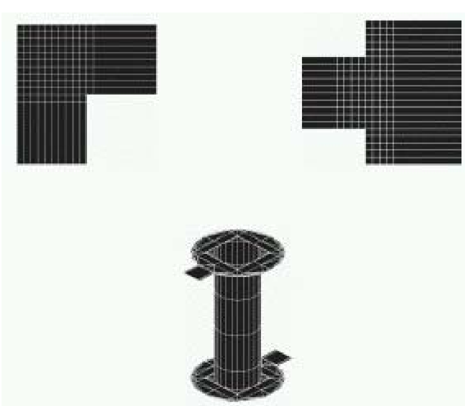


Figure 3 - PWB Discontinuities (Corner, Step in Width, Via)

In this way a designer can transfer the RLCG circuit in SPICE format directly to circuit simulators and has the possibility to analyse the behaviour of the electronic assembly taking into consideration also the influence of metallic passive interconnection structures, which are usually considered as ideal items. The virtual evaluation allows a better prediction regarding the real working of the PWB assembly in practice.

The discontinuities are physically connected through microstrip transmission lines, which are in fact the copper tracks or realize the connection between tracks and pads (PTH pads, SMD pads and via capture pads).

Simulation Results

In this section results and running parameters of the simulation process are presented. Some simulation parameters were the following: a) gridding frequency=20 GHz; b) automatic edge cell width= 1 mil; c) meshing optimization enabled; d) # GHZ, Z_{RI} ,R=50; e) Nport= 2. The time steps duration was determined by the minimum grid size and the maximum frequency. The necessary number of time steps was determined by multiple tryouts in order to observe a good convergence. The simulation time depends normally on computer clock speed. If parameters are adequate, we can proceed to extract the S parameters and LC equivalent circuits.

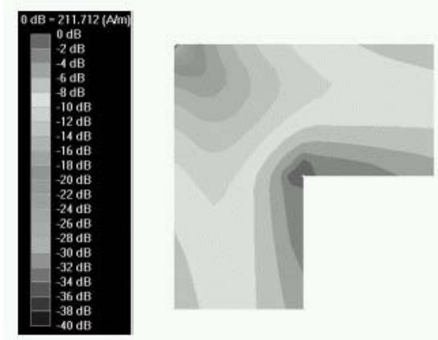
S parameters are sometimes difficult to be interpreted. More interesting are the results obtained for the LC lumped parameters. The results for a 12 mils via are presented in Table 1. The excitation signal was of 1V, the incident wave phase being zero.[1] “Grid Generation” has created 286 cells and a simulation CPU time of 87-97 s was obtained.

Table 1 - LC Lumped Spice Model for a 12 mil via (FR4 structure, h= 60 mils, t= 17.5 μm, ε_r= 4.66)

Parameters→ Frequency (MHz) ↓	**L_P (nH)**	**C_P (pF)**
50	1.469	0.5186
100	1.468	0.5187
200	1.467	0.519
500	1.46	0.5205
800	1.452	0.523
1000	1.444	0.5252

In Figure 4 3D average current densities of the simulated entities are presented.[1,4] All the parameters specified in the first section are available for future research and study.

The previous activities were performed only based on rigid PWBs but there is not a problem to prepare and analyze geometries also for flexible PWBs. The authors did a few tests using two flex materials, one in which the dielectric is 0,125mm thick[5] and the other having a dielectric thickness 0f 0.3mm thick[6].



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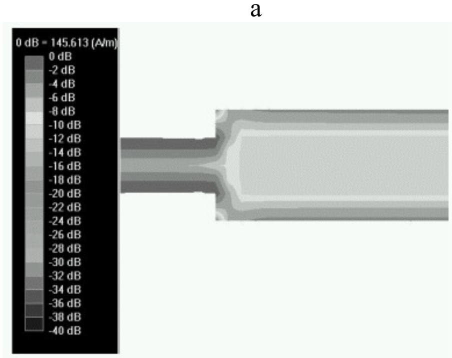

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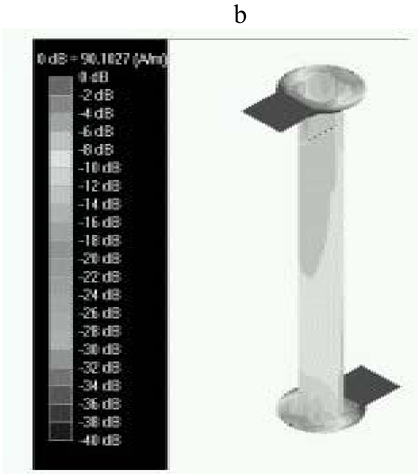

c

Figure 4 - 3D Average Current Densities (a- Corner in a trace of 10 mils, b- Step in Width between 8 and 16 mils Traces, c-12 mils Via)

The first material is a heat-conducting and electrically-isolating single component polymer, filled with a ceramic/heat-conducting special material. Normally, the flex laminate is a single copper layer structure[5] but it is possible to create also double sided laminates. The second material is a polyimide foil which can lead, after the manufacturing process, to single layer or double layers laminates for PWB assemblies applications.[6] The copper layer is directly connected to the polyimide substrate. In order to realize some comparisons with rigid structures, the two materials from above were evaluated from the "step in trace width" discontinuity point of view (see Figure 3). The first segment width is of 8 mils and the second segment of 24 mils (Tables 2-4). The dielectrics are of 0.125 mm and0.3 mm thick for the flexible materials and 1.5 mm thick for standard rigid FR-4. For all cases the copper foil thickness is of 35 μm.

After full-wave electromagnetic simulation and LC parameters extraction the following results were obtained:

Table 2 - LC Lumped Spice Model for a 8→24 mils "Step in Width" (Rigid FR4)

Parameters→ Frequency (MHz) ↓	L_P (nH)	C_P (pF)
10	0.259	0,039
20	0.258	0,039
50	0.256	0,039
100	0.253	0,039
200	0.252	0,039
500	0.251	0,039
1000	0.249	0,039

Table 3 - LC Lumped Spice Model for a 8→24 mils "Step in Width" (0.125mm thick)

Parameters→ Frequency (MHz) ↓	L_P (nH)	C_P (pF)
10	0.143	0,044
20	0.142	0,046
50	0.140	0,057
100	0.138	0,090
200	0.137	0,080
500	0.135	0,077
1000	0.135	0,075

Table 4 - LC Lumped Spice Model for a 8→24 mils "Step in Width" (0.3mm thick)

Parameters→ Frequency (MHz) ↓	L_P (nH)	C_P (pF)
10	0.197	0,086
20	0.196	0,086
50	0.193	0,086
100	0.191	0,086
200	0.189	0,086
500	0.188	0,086
1000	0.187	0,086

Regarding Z_0, the step in width leads to a step in characteristic impedance as follows: 122.5Ω to 98.08Ω (standard rigid FR4), 58.33Ω to 29.46Ω (0.125mm thick flex) and 65.26Ω to 38.19Ω (0.3mm thick flex) and which can cause reflections due to the mismatch in the signal path.

The results from above and a large quantity of other simulation data can be stored in a models library, which is useful for evaluating of printed circuits structures and future design activities.

Models Library

In this paragraph the library of electromagnetic models for PWB structures is presented. Input data for the application are bitmap files, tables, graphs and pictures. The steps are in Figure 5 presented.

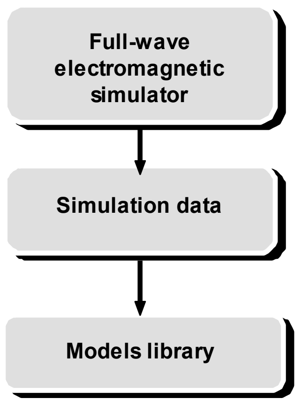

Figure 5 - Data Storing in the Models Library

There were considered five structure types: corner (right-angle bend), trace, T-junction, via and step in width. Input data for each structure type are the following parameters:

- **W** – trace width;
- **H** – dielectric thickness;
- **Er** – dielectric permittivity;
- **tg d** – loss tangent;
- **t** – Cu thickness;
- **D** – pad diameter;
- **d** – drill diameter;
- Bitmap files for S, Y, Z parameters;
- Bitmap files for current density, radiation pattern and information.

The library consists of two distinct applications: one for data file setting up and modification, and the second for structures presentation. Objects are in an array file stored. The application extracts the information attached to each object for screen presentation, following the steps: structure type selection, structure selection and data selection for view.

The user interface is in Figure 6 presented. In the upper area of the window are 5 tabs, corresponding to the 5 structure types. Selecting a structure, in the right side of the library window the parameters W, Er, H, tg d and structure view are presented. For each PWB discontinuity S, Y, Z parameters, current distribution, LC-Model or radiation pattern are available for future evaluation.

For current density/radiation pattern display, the designer can select (from the right side list), the frequency of interest, by pressing the appropriate radio button (Figure 7). The button "Information" presents, in a new window, additional data regarding the structure.

The interface for new items generation (called "Creation") is in Figure 8 shown. It is divided into several fields. Type and parameters of a specific structure can be step by step defined. The user has the possibility to specify the model and to configure the assignments for it.

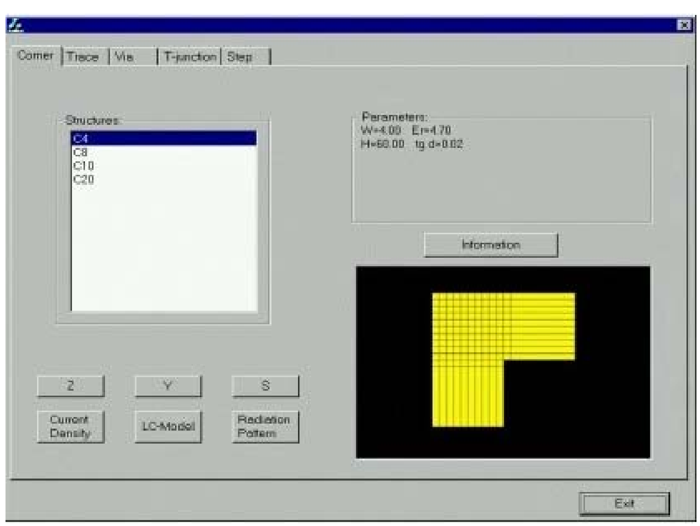

Figure 6 - The Library User Interface

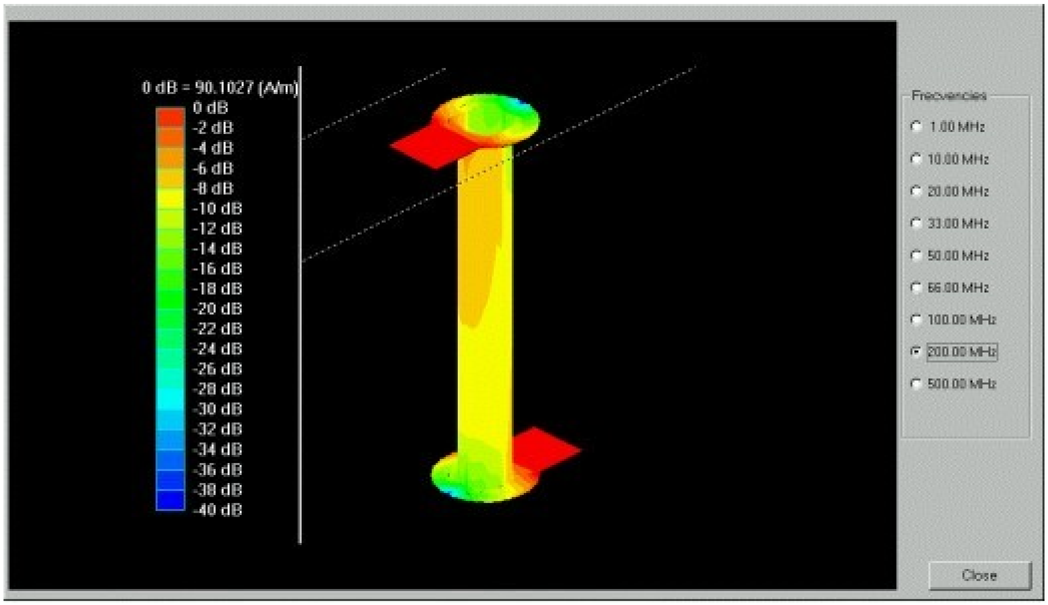

Figure 7 - Current Density for Via V16-8 (W=8 mil, H=60 mil, Er=4.70, tg d=0.02 D=16 mil, d=8 mil) at 200 MHz

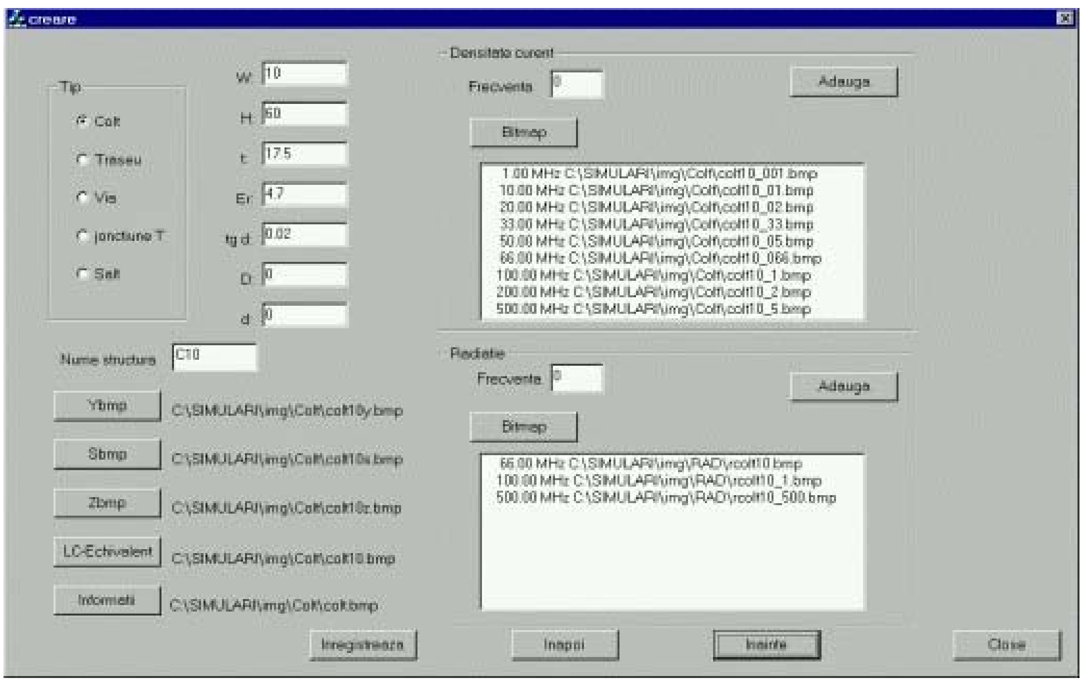

Figure 8 - "Creation" Interface

In different fields as "Current density", "Frequency" or "Bitmap" one can be introduced the behavior of the model at various frequencies and the associated pictures in order to offer a better capability of using in practical projects. Pressing the "Add" button the model will be enlarged with new data, depending on the requirements. The field "Radiation" is very similar with "Current density" but it refers to the specifications regarding the far field radiation maps. If the button "Recording" is pressed, the simulated data are in the fields of application introduced and in a model file stored.

Manufacturing of Test Boards

The manufacturing of some test boards was realized using both standard chemical - electrochemical process and special method as milling gaps around the metallic interconnection structures. Below, the second technique, which is very suitable for prototyping in university labs, shall be presented. Because one of main activities developed in CETTI, IPC member since 1997, is focused on PWB level, the team has developed an electronics technology laboratory in which one direction is based on SMT equipment, repair & rework stations, optical inspection and various types of tests. The second, the newest one, built last summer, is based on LPKF-Protomat M100/HF equipment, a circuit board plotter which, has the capability of PCB prototypes manufacturing by milling and drilling.[7,8,9]

In Figure 9 the data flow between CAD and prototyping is presented. After the PWB design phase, the virtual printed circuit board is obtained. The CAD/CAM manufacturing files are prepared during the post-processing procedure. These files are the inputs for the prototyping laboratory, the outputs being the production of real boards, using LPKF plotter.

The interface between manufacturing files (Figure 9) and the prototyping equipment is realized with a software tool, which combines two important domains of electronics technology: CAD and CAM. The program can be used for the import, checking and editing of CAD/CAMfiles, calculating the isolation gaps between the conductive traces, performing optimizations and export the new created file in a special format (LMD - LpkfMillDrill) for the link with the software tool for control and command of the plotter.

The sequence of technological steps performed with the help of the interface CAD/CAM tool is the following[7]:

- Import of manufacturing files;
- Preparation of special production file for interfacing with the prototyping equipment;
- Export of production file.

A very important task during this step is the isolating procedure (Figure 10), which can be realized with the default jobs or using a custom preparation.

Finally, the processed manufacturing data can be exported to the plotter control/command softwarein order to realize the production of PWB prototypes.[7] It accepts data exported by the CAD/CAM Interface softwareand realizes the automatic control and driving of the circuit board plotter. It works also with standard HPGL files generated by CAD software systems. The practical steps for producing the real boards are as follows:

- Configuring the plotter control/command software and saving the parameters in an INI file
- Defining the serial interface for the link with the plotter
- Configuring the plotter and drilling/milling parameters
- Specifying the board size
- Creation the job for processing
- Import of LMD file
- Preparation of the project for plotting, generation of panelization, if necessary
- Start the plotting.
- At the end the boards are fully manufactured.

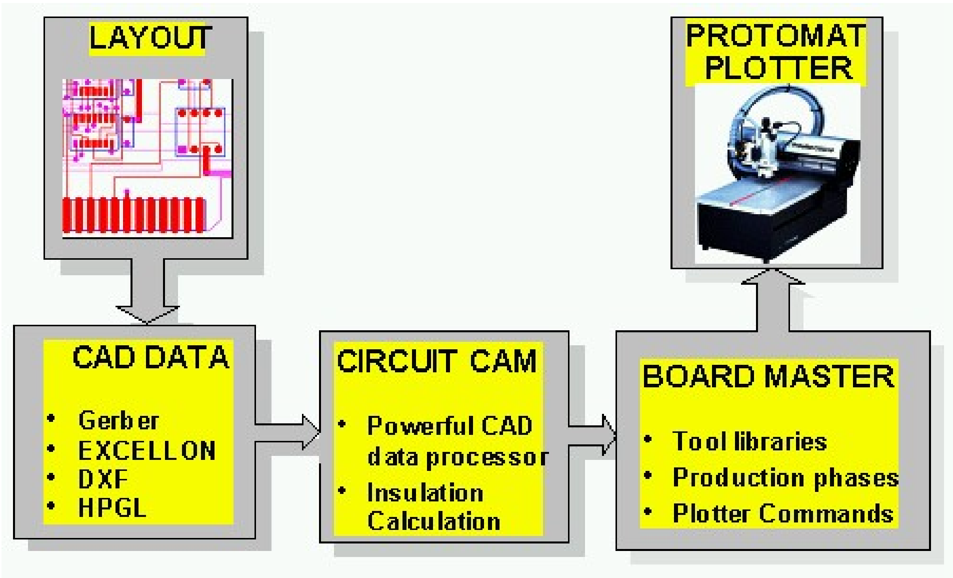

Figure 9 - Data Link Between CAD and Prototyping

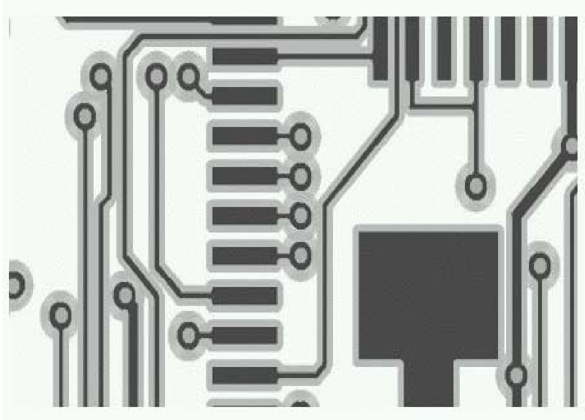

Figure 10 - Board with Isolations

In the frame of a student labs series, CETTI has generated a complete design and fabrication flow in which the future engineers can understand the development of electronic modules/assemblies from the very beginning stage (schematic capture) and till the manufacturing of boards, components placing/soldering and electrical testing & various other checking. A very important issue is the electromagnetic simulation on which is focused this paper. The students have the opportunity to learn from the university the key topics of modeling and full-wave simulation and to learn about the dramatic impact of PWB structures on current electronic modules and assemblies.

Conclusions

PWB structures were modeled and simulated from electromagnetic viewpoint. The models were obtained by partitioning the structure in 2D layered finite elements. The electromagnetic simulation was based on Method of Moments. This makes it suitable for modeling mostly 2D structures. The simulations were performed at various frequencies of interest.

At the end LC/RLCG lumped parameters were extracted. It was observed that values of LC elements do not vary much within the frequency range till 1 GHz. The work has given the opportunity to the Romanian design team participating at an INCO Copernicus European Project to observe the capability to model/simulate various types of planar or 3D structures present in electronic products. This performance technique seems to be an accurate investigation software tool in order to realize high quality education and research in the field of metallic interconnection structures and to design better assemblies destined for high frequency/high speed applications.

Acknowledgments

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