01 Aug 1996

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Recommended Citation

T. H. Hubing et al., "An Expert System Approach to EMC Modeling," *Proceedings of the IEEE International Symposium on Electromagnetic Compatibility (1996, Santa Clara, CA)*, pp. 200-203, Institute of Electrical and Electronics Engineers (IEEE), Aug 1996.
The definitive version is available at https://doi.org/10.1109/ISEMC.1996.561228

An Expert System Approach to EMC Modeling

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Abstract - Existing computer software for EMC analysis can be divided into three categories. *Analytical modeling codes* employ closed form expressions to solve problems of general interest to EMC engineers or circuit designers. *Numerical modeling codes* use numerical techniques to solve Maxwell's equations subject to specific boundary conditions. *EMC rule checkers* search a design for features that violate basic EMC design guidelines. This paper outlines the relative advantages and limitations of each of these three approaches and describes an *expert system* EMC modeling approach. The new approach combines analytical models, numerical models, and EMC rule-checking in order to evaluate designs in much the same way that an EMC expert would.

INTRODUCTION

Experienced EMC engineers are understandably skeptical of any vendor claiming to sell electromagnetic modeling software that predicts levels of radiated EMI. Although there are a large number of software tools available to help EMC engineers and circuit designers meet EMC requirements, it is not realistic to expect software to accurately predict the outcome of FCC or European EMI tests. One reason for this is that software tools do not have all the information available to them that is necessary to do an accurate calculation. EMI modeling software may be able to get board geometry information from automated board layout tools, but it is still missing important information such as,

- signal frequency and risetime on each net
- actual (as opposed to nominal) component values
- enclosure geometry, aperture location, quality of seams
- on-chip parameters (e.g. internal decoupling, lead inductance)
- cable length, type, placement
- out-of-band component properties.

The information above plays a significant role in determining the levels and frequencies of radiated EMI. Subtle changes in any of these properties can have a great impact on the radiated emissions at any particular frequency.

Another reason that software cannot predict the outcome of an actual EMI test is that EMI testing is not a particularly stable or repeatable process. An IBM study described in a 1992 paper [1] evaluated 44 EMI test sites using a small dipole source with a fundamental frequency of 10 MHz and harmonics up to 600 MHz. Although the source was shown to be stable to within ± 1.0 dB, the study found that "... over 60 percent of the sites had one or more frequencies with differences of over 5 dB from the mean." Differences between any two sites were often much greater. At some frequencies, the expected deviation between any two sites exceeded 15 dB.

Clearly it is unreasonable to expect EMC modeling software to predict the outcome of an EMI test to within a few dB. Nevertheless, there are a number of computer modeling codes available that can be invaluable to EMC engineers and circuit designers who want to understand or avoid EMC problems with their design. Computer modeling tools can be used to provide information about a particular design that is not readily obtained in any other manner. For example, computer modeling tools can calculate values of parasitic inductances and capacitances in a circuit, model the behavior of the radiated fields, determine current distributions, calculate crosstalk, evaluate the effectiveness of a shielded enclosure, or locate simple design mistakes.

Generally, software tools for EMC analysis fall into one of three categories: analytical modeling codes, numerical modeling codes, or design rule checkers. Analytical modeling codes use closed-form equations and/or pre-calculated solutions to analyze EMC problems. Numerical modeling codes analyze problems by numerically solving Maxwell's equations subject to particular boundary conditions. Design rule checkers scan a printed circuit board or system design for errors or violations of EMC design guidelines.

ANALYTICAL MODELING CODES

Analytical modeling software, which uses relatively simple closed-form expressions to calculate parameters such as field strengths or currents tends to be relatively fast and easy to use. Analytical methods fit problems to pre-defined geometries with known solutions. This type of software might be used to calculate the crosstalk between two signal traces, calculate the radiated field strength from a given trace geometry, or estimate the amount of power bus noise on a poorly decoupled printed circuit board. Analytical modeling codes are generally faster and easier to use than general purpose numerical modeling codes or design rule checkers. However each code has a limited set of functions and it is generally up to the user to ensure that a particular code can be correctly applied to the problem at hand.

NUMERICAL MODELING CODES

Numerical electromagnetic modeling software is widely viewed as a promising new tool to help EMC engineers and circuit designers anticipate electromagnetic compatibility problems. Numerical EM modeling codes solve field equations subject to appropriate boundary conditions in order to determine the electromagnetic behavior of different source configurations.

The ability of a numerical modeling code to model a particular geometry is largely dependent on the numerical technique(s) employed by the code. Finite element modeling codes (e.g. MSC/ EMAS or AnSoft's MAXWELL codes) excel at modeling relatively complex geometries with lossy or even nonlinear materials. Codes that employ surface integral techniques (e.g. NEC, COMORAN, HFSS, EM, IE3D, COMPLIANCE, MAXSIM-F) are very well suited for modeling relatively large, resonant structures; particularly structures with long wires or cables. Finite difference time domain (FDTD) codes (e.g. XFDTD, EMA3D, EMIT) are usually the best choice for time domain or broad-band modeling.

Three-dimensional, full-wave, EM modeling software can be used to solve for the currents and fields in configurations that closely approximate a variety of EMC problem geometries. Unfortunately, full-wave 3D analysis can be computationally expensive, which limits the size and complexity of problems that can be analyzed. Static or quasi-static 3D EM software is more computationally efficient permitting problems of greater complexity to be analyzed, but it cannot be used to analyze electrically large structures or calculate radiated fields.

Two-dimensional EM modeling software is much more efficient and easier to use than three-dimensional EM modeling software. Two-dimensional EM modeling software can be used to analyze transmission line structures or structures with rotational symmetry. It is well suited

0-7803-3207-5/96/$5.00 © 1996 IEEE

for modeling signal propagation on cables or printed circuit boards and can even be used to predict the radiation due to differential currents on these structures. However, it is not able to accurately calculate or estimate the common mode currents that generally have the greatest impact on radiated EMI.

Several software vendors have packaged numerical modeling software with software that automatically extracts printed circuit board geometry data from automated board layout tools. These tools make it easier for EMC or signal integrity engineers to take advantage of numerical modeling software. Other vendors have developed software environments that bring together a variety of numerical modeling tools with a common interface designed specifically for EMC engineers.

Despite the availability of software that models geometries of interest to EMC engineers with a high degree of accuracy, numerical codes have not been widely utilized for EMI modeling. Only a small percentage of EMC engineers use numerical modeling codes on a regular basis. One reason for this is that numerical codes require well defined sources. Defining the source of an EMC problem is often the most difficult step in the solution process. When an EMC engineer can identify the parameters necessary to do a numerical analysis (i.e. source location, source amplitude, and antenna geometry), then often the problem can be corrected without doing a numerical analysis. Numerical electromagnetic modeling codes are sometimes used to analyze specific circuits or structures, but typical printed circuit board configurations are much too complex to be analyzed in their entirety using strictly numerical methods.

There is an additional problem with existing numerical EM modeling codes that often prevents them from being used, even in cases where relatively simple well-defined model geometries can be identified. Existing modeling codes have a fairly steep learning curve. The user must be reasonably well versed in the procedures for applying the code as well as the techniques used by the code and their limitations. Few EMC engineers can afford to be an expert user of several EM modeling codes that may or may not be occasionally helpful. Numerical EM modeling codes are potentially a very valuable tool for EMC problem analysis, but in their present form they require too much expertise on the part of the user to be widely used for EMI modeling.

RULE CHECKING CODES

EMC rule checking software reads board layout information from automated board layout tools and looks for violations of basic EMC design rules. This type of software does not usually attempt to predict the electromagnetic behavior of the system, but instead is intended to help designers avoid costly mistakes early in the design stage. EMC rule checkers can help board designers to locate potential problems with their designs and they can also help experienced EMC engineers to quickly identify problems that would otherwise be hard to spot.

Unlike numerical and analytical modeling software, rule checkers do not require the user to understand basic principles of electromagnetic modeling. However, the available rule checking codes do require the user to identify critical nets and supply information about the signal parameters. This requires a certain amount of expertise that most potential users of EMC modeling software do not have. Another difficulty with rule checkers is that design rules and their impact on EMC can vary significantly from one design to another. Design rule violations that are a major problem for one design may be of little consequence in another design.

EXPERT SYSTEM CODES

Although each of the techniques above can be a very powerful tool in the hands of a knowledgeable user, software employing these techniques is not widely used by EMC engineers or circuit designers. The learning curve associated with available tools is often too steep. Few engineers have the knowledge and experience required to use these tools effectively.

To circumvent this problem, a new class of EMC software utilizing expert system techniques is currently being developed at the University of Missouri-Rolla. This new class of software attempts to emulate the thinking process of experienced experts in EMC and does not require the user to have any expertise in EMC or circuit design.

An expert system is an interactive computer-based decision tool that uses both facts and heuristics to solve difficult decision problems based on knowledge acquired from an expert [2]. An expert system may not only arrive at conclusions or make recommendations, but can also give the user a level of confidence in the solution.

While it may be unreasonable to expect computer software to predict the outcome of an EMI test, EMC engineers are asked to do this on a regular basis. Early in the design stage, EMC engineers must be able to anticipate problems, estimate the severity of these problems, and suggest design changes that will bring the product into compliance. Although no one can predict the outcome of an EMI test within a few dB, experienced EMC engineers do a pretty good job of recognizing which products are likely to fail and which products should be OK.

By emulating the thinking process of an experienced EMC engineer, expert system software will be capable of making design decisions similar to those that would be made by a human EMC expert. The primary task in developing an EMC expert system is understanding this thought process and implementing it in software.

EMC EXPERT SYSTEM STRUCTURE

EMC engineers rely on four basic sets of information as input to any decisions they may make regarding the requirements of a particular electronic design. These are,

- information about the design (schematics, layout, enclosure...)
- design guidelines
- experience with past designs
- results obtained from numerical or analytical models

One engineer may rely more heavily on one set of information while another engineer depends more on another, but the most successful EMC engineers will utilize information to some extent from each of these areas. If information in one of the areas is missing, the EMC engineer must make the most of the information available. However if too much information is missing, the assessment of the overall design will not be as accurate as it could be.

Figure 1 shows the basic structure of the EMC expert system algorithm being developed at the University of Missouri-Rolla. Essential features of this algorithm are being implemented in software that is currently under development by Quad Design Technologies, Inc.

Like an EMC engineer, the expert system starts by gathering all of the information about a design that it can. Information about the board geometry is obtained from the automated board layout tools. Information about intentional or unintentional signals on specific nets is deduced from the information available in an EMC library file. Information regarding past experiences with similar products or industry-specific EMC problems is contained in an EMC personality file.

The EMC library file contains information on components and circuits that is not available in the board layout files. The information in this file helps the expert system to track and characterize signal currents. Most of the information in this file is readily obtained from component data sheets, but EMC-specific information can also be included. For example if a certain active component was known to have inadequate internal decoupling resulting in high-frequency noise appearing on the

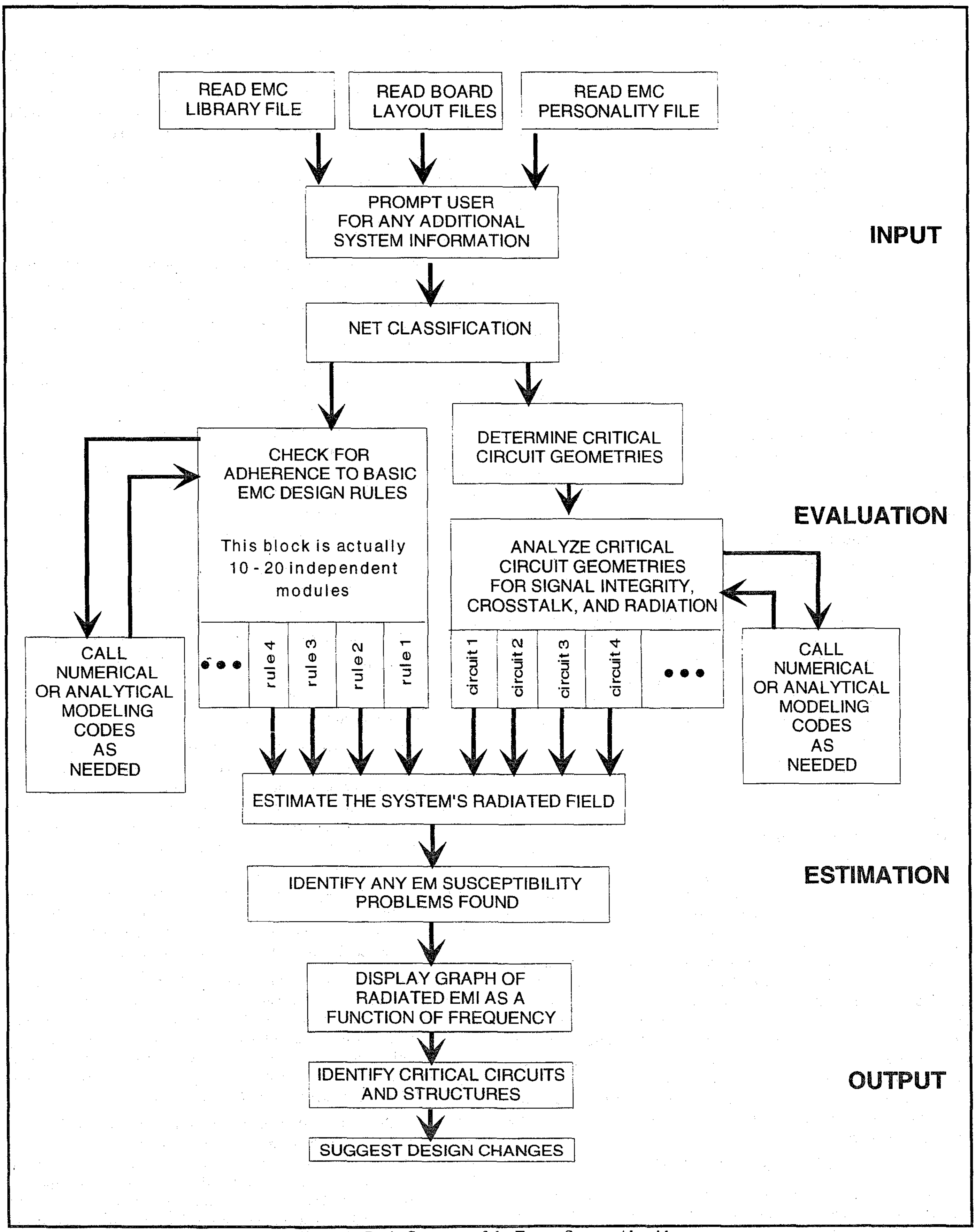

Figure 1: Basic Structure of the Expert System Algorithm

low-frequency outputs, this information would be stored in the EMC library file. Typically, each company would have their own EMC library file and this file would be periodically updated by the company's EMC or CAD department.

An EMC personality file is necessary because different industries have different design requirements and different EMC design strategies. A company that designs 4-layer boards for the automotive industry will have to do things differently than a company that designs 12-layer boards for the computer industry. The EMC personality file contains the information that helps the expert system algorithm to recognize industry standard circuits, decide which design rules are the most important, and make appropriate design compromises when necessary.

Since the user of this software might be a circuit designer, a board layout person, an EMC engineer, or someone else; the software cannot assume that any particular piece of information is available from the user. Nevertheless, the user can be a valuable source of information in many cases. Therefore, the algorithm allows the user to provide input, but does not require it.

Once all of the information about the design is gathered. The net classification algorithm takes over. Using the data from the board layout files, the EMC library file, and the EMC personality file; the net classification algorithm determines information about the signal properties, waveforms, noise margins, and the function of each net.

At this point the algorithm branches into two independent paths. Along one path, the algorithm works like a design rule checker. The design's compliance with various EMC design guidelines is evaluated and violations are quantified and ranked. Along the other path critical circuit geometries are identified and evaluated. Much like an EMC engineer, these critical circuit subroutines look for possible antennas and try to evaluate the sources that drive them. They also look for possible sources and try to identify and quantify the antennas that they might drive.

All of the subroutines utilized by the expert system code are designed to do the best that they can with the information available. If a particular piece of information is missing, the impact of the missing information is recorded, but the algorithm continues to evaluate the design.

Once the evaluation of the board is complete, the algorithm puts together all of the relevant data to compile an estimate of how much the board is likely to radiate once it is installed and operational. This estimate is reported in the form of a radiated EMI plot similar to that which would be obtained from an actual EMI measurement. A shaded background is used to indicate the confidence of the estimate at any given frequency. This format was chosen because it contains all of the pertinent information in an intuitive manner and is easily understood by people with different engineering backgrounds. It must be clear to the user of the software that this is the best estimate the code could make with the information available and not a guarantee of the product's performance in an actual EMI test.

Because of the way the algorithm is structured, all of the variables that affected the estimate at any frequency are known. Therefore, it is possible to construct a ranked list of all the design rule violations and/or critical geometries that contributed to the radiated EMI at any given frequency. For example, clicking on one of the frequencies in the radiated EMI plot, could open a window that lists the design changes that would be most effective at reducing emissions at that frequency.

A diagram of the board layout showing all of the nets color-coded to indicate problem areas can also be displayed. Susceptibility problems as well as radiation problems can be flagged in this diagram. Clicking on a problem area could bring up a window that describes the EMC problem and suggests a simple solution.

CONCLUSION

There are a number of software tools that can help product developers to meet their EMC requirements. Modeling codes that employ numerical, analytical, or rule checking techniques can analyze a wide range of EMC problem geometries and are readily available. To the experienced user, these codes can be valuable EMC design tools. However, the most useful tools require a certain amount of expertise on the part of the user, which prevents these tools from being widely utilized.

The EMC expert system algorithm described above does not require the user to be familiar with EMC, the board layout, or the circuit design. Like a human EMC expert, the algorithm learns all it can about the design, applies design guidelines, evaluates possible sources and antennas, and evaluates the design to the best of its ability. Like an EMC expert, the more information the algorithm has about a particular problem, the more effective its analysis will be.

EMC expert system codes won't eliminate the need for other types of EM modeling codes. They also won't eliminate the need for human EMC engineers to be involved in the design process. Nevertheless, due to their ease-of-use and their ability to quickly identify EMC problems, they are sure to play a significant role in the future of EMC engineering.

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