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Expert System Algorithms for EMC Analysis

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Abstract – Expert system algorithms that analyze printed circuit board designs, anticipate EMC problems, and help designers to correct these problems are being developed by the EMI Expert System Consortium at the University of Missouri-Rolla. This paper reviews the basic structure of the EMI expert system and describes newly developed algorithms.

Introduction

In order to achieve the short development cycles that are necessary to be competitive in the electronics industry, it is becoming increasingly important to get the design correct before the first prototypes are built. This means that printed circuit board designs must be capable of meeting radiated EMI and EM susceptibility requirements the very first time they are tested in a lab. Experienced EMC engineers with a detailed knowledge of a printed circuit board design can often identify potential EMC problems in a design, evaluate the severity of these problems, and help designers to correct them before a prototype is built. Unfortunately, most companies cannot afford to have an experienced EMC engineer looking over the shoulder of the designers at every phase of the design process.

Expert system EMC software is designed to help provide EMC expertise to circuit designers and the people who do printed circuit board layouts. Expert system EMC software reads data from automated board layout files, component files and an EMC knowledge database. It then uses this information to find and evaluate potential EMC problems. Unlike numerical EM software or design rule checkers, expert system software is capable of identifying and quantifying critical EMC problems and helping the non-expert user to solve them.

The following sections describe the ongoing work of the EMI Expert System Consortium at the University of Missouri-Rolla. The consortium consists of hardware and software companies who are working with the university to develop expert system software for EMC analysis.

The EMC Expert System

Figure 1 shows the basic structure of the EMC expert system. The shaded boxes represent those algorithms that have been implemented. The expert system consists of four stages – the input stage, the evaluation stage, the estimation stage and the output stage. Each stage is made up of several modules, with each module performing a certain task. This modular structure makes it easy for a person to understand and modify the functional capability of the system.

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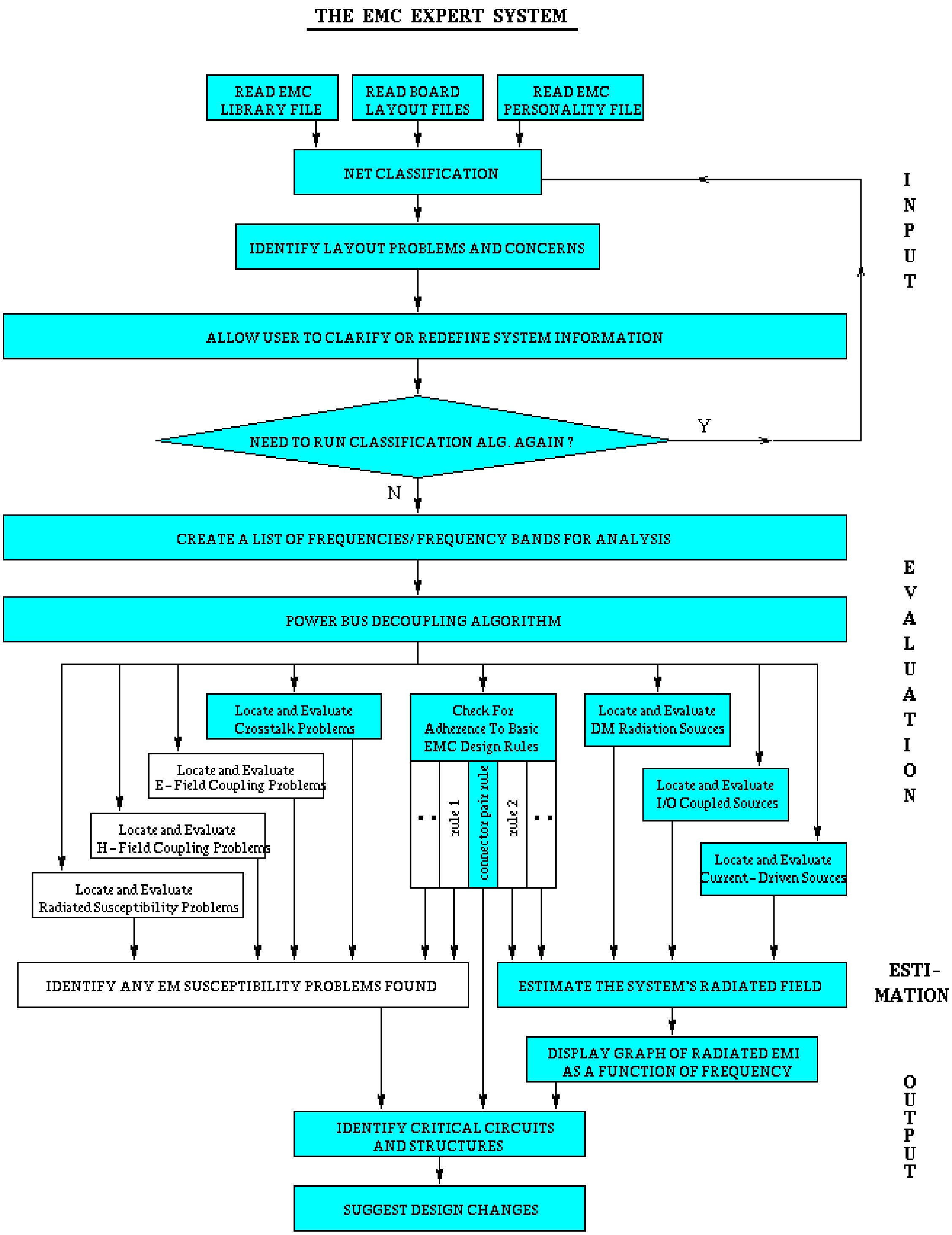

Figure 1: EMC Expert System Flow

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The Input Stage

Information about the printed circuit board under analysis is collected by the input stage of the expert system. Physical information about the board, such as board geometry, names and locations of all nets and components, trace lengths and thicknesses etc., is obtained from board layout files generated by automated layout tools. The electrical properties of each net, such as signal frequencies, currents, voltages etc., are deduced by collating information from the layout files and the *component library*.

The component library is a file that contains information about components that is not present in the board layout files. It is a database of information about all components that the system may encounter when analyzing PCB's for a particular set of users. The component library contains component information at two levels – the package level and the pin level. Package level information about a component includes the component name, package size and type, pin pitch etc. Pin-level information about a component is provided for each pin of the component and varies depending on the type of component and the function of the pin. For example, each output pin of an active digital device would have an entry in the component library that specifies the risetime, maximum voltage, maximum current, clock frequency, and type of signal (e.g. data, clock, etc.).

A third source of information for the expert system algorithms is the *EMC personality file*. This file is used to tailor the expert system software to meet the needs of a particular company. The EMC personality file contains industry-specific information that controls the way the expert system algorithms execute. It also contains information that helps the expert system to recognize circuits and structures commonly used by a particular company.

The data from the layout files and the component library is used by the *net classification* algorithm to determine information about the signal properties, noise margin and function of each net on the board. It also searches for possible layout problems, such as nets being referenced to more than one power source, or nets being driven by more than one driver, and alerts the user to such problems. The algorithm identifies all power and ground nets on the board by checking each net to see if any of the pins attached to it are specified to be power or ground in the component library. Nets that are neither power nor ground are called *signal* nets.

The classification algorithm determines various signal parameters for each signal net. These parameters are determined from the component library entry for the driver for the net. The algorithm locates a driver by checking to see if any active device output pin is connected to the net either directly or through passive devices. The signal parameters determined by the classification algorithm consist of the clock frequency associated with each digital net, the range of signal frequencies on each analog net, the signal transition time for each digital net, the maximum and minimum voltages on each net, the maximum current on each net, the reference voltage for each net, and the utilization classification of each net.

Each signal net is also assigned a *noise margin*, which is the maximum voltage that may exist on the net without interfering with the normal behavior of the components. This assignment is based on the noise margins of the active device input pins on the net, as specified in the component library.

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After the classification algorithm finishes its run, its results are made available to the user, who is given a chance to modify the results, or provide information that may fill in any gaps in the available information. At no point does the expert system ever require the user to provide information about the circuits or board design. If the user is satisfied with the results of the net classification, these results are passed to the evaluation stage of the EMC expert system.

The Evaluation Stage

The evaluation stage of the expert system contains the modules that perform a detailed EMC analysis of the board. These modules search for potential radiation and susceptibility problems with the board, and also test the board for compliance with basic EMC design guidelines

The expert system creates a list of all the clock frequencies on the board, and their harmonics, and all narrow-band analog signal frequencies. The narrow-band radiation from the board is calculated at these frequencies only. The frequency spectrum is also divided into blocks at which the broadband radiation is calculated. These blocks are created in such a way that each block is centered at a narrow-band frequency, and fills the space between narrow-band frequencies.

The *power bus noise* algorithm estimates the voltage induced on the power bus of printed circuit boards that utilize power and ground planes. This estimate is based on information about the currents drawn from the power bus by the active devices and the effective decoupling at each frequency of interest. A time-domain analysis is used to predict the peak voltage induced on the power bus and a frequency-domain approach is used to determine the noise on the power bus as a function of frequency. Power bus noise information is utilized by other algorithms and therefore the power bus noise algorithm must be run before the remaining algorithms in the evaluation stage.

The basic approach used by the expert system to locate and quantify radiated EMI problems is to locate all possible sources of high-frequency energy and all structures likely to radiate that energy. Different algorithms are used in the evaluation stage to locate different kinds of EMI sources.

The DM radiation source algorithm searches for signal nets that carry high-frequency currents and are long enough or large enough to serve as their own antenna. DM refers to *differential-mode* radiation sources. Differential-mode sources are rare on well-designed boards, but they are relatively easy to locate and quantify.

I/O coupled sources are fairly common, particularly on dense boards with many signal layers. An I/O-coupled source results when signal energy from one net couples to another net that carries this energy off the board. The expert system algorithms look for both magnetic and electric field coupling between nets with high-frequency signals and nets that attach to connector pins.

The most common radiated EMI problems below about 500 MHz are due to *current-driven* sources. Current driven sources result when signal return currents create a small potential difference between two points in the ground structure. This potential difference can create currents in cables or enclosures attached to ground that result in radiation. The expert system estimates the two-dimensional voltage variation across the return plane structure, due to currents returning on the power and ground planes. It then locates the antennas that may be driven by this voltage variation.

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The expert system is capable of identifying antenna configurations such as a cable being driven relative to another cable or a heatsink, a cable or heatsink being driven relative to the board etc. For each such antenna, it determines the voltage difference between the two halves of the antenna, and then calculates the E-field radiated from the antenna at each narrow-band and broad-band frequency.

Algorithms are also included that identify crosstalk problems and check the design for violations of basic EMC design guidelines.

The Estimation and Output Stages

The results from all the modules in the evaluation stage are passed to the estimation stage, which combines these results to form an overall estimate of the radiated EMI from the board. The radiated EMI modules in the evaluation stage calculate the magnitudes of the electric fields due to each of the radiated EMI mechanisms, at each frequency and frequency block.

The output stage presents the expert system's evaluation of the board to the user. It displays a graph of the estimated radiated EMI as a function of frequency, and identifies the circuits and structures on the board that are mainly responsible for the board's radiated EMI problems. It also suggests design changes that will alleviate the problems reported.

The radiated EMI plot displayed by the expert system is similar to that which would be obtained from an actual EMI test. It plots the board's radiated field in dB(μV/m) as a function of frequency. An FCC or CISPR limit line is placed on the plot, so as to give the user an immediate idea of the frequencies at which the board radiation exceeds the limit, and the amount (in dB) of excess radiation at those frequencies.

Significant contributions of individual nets to the radiated E-field are recorded at each frequency by the modules of the evaluation stage. These are used to construct a list of nets causing the worst problems at any particular frequency. So, if the user would like to know which nets are causing the radiation to exceed the limit at any frequency, the expert system can list all such nets and display a diagram of the board layout that highlights these nets. Information about the mechanisms that cause these violations is also available to the user.

The expert system also offers suggestions that will help in reducing radiated EMI levels. As the chief contributors to the emissions are known to the system, it uses simple rules to come up with viable suggestions that will reduce the contributions from the worst offenders.

New Algorithms

The next prototype software will contain improvements to the existing algorithms based on evaluation of these algorithms against actual hardware. Improvements to the current-driven algorithm will reduce the probability that this algorithm will be fooled by an unusual component placement. Also voltages induced in the power and ground planes by the components themselves will be estimated in addition to the voltages induced by the currents through the traces.

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Experiments using real computer hardware in the laboratory have shown that radiation at frequencies near 1 GHz is dominated by different source mechanisms than radiation below 500 MHz. At the higher frequencies, enclosure resonances play a critical role in the way that products radiate. A new algorithm has been developed to predict and analyze radiated emissions at frequencies above 500 MHz in products with metal enclosures.

The next prototype software will also use a different method to sum the contributions from the various EMI sources that are identified. The original version used a root-mean-square sum of the field strengths resulting from each individual source-antenna combination. However, the algorithms assume that the cables are oriented in the position that "tends to maximize" radiated emissions (per the FCC and CISPR test procedures). Since it is not usually possible to find a cable position that maximizes the contributions from all sources at the same time, this root-mean-square summing technique has been shown to be too harsh. The new algorithms will sum all of the sources to determine their relative contribution, but the level reported to the user will be the predicted emissions from the worst-case source-antenna pair at each frequency.

Summary

The EMC expert system described in this paper models the thinking process of a human EMC expert. It reads board layout information and information about the components on the board. It uses information stored in its knowledge base (i.e. the component library and the personality file) to deduce properties of the signals on each board trace. This information is used to identify and evaluate possible radiation sources and antennas, and provide an overall estimate of board radiation and board susceptibility.

The EMC expert system is not designed to replace human EMC experts. However, it provides a means of automating many of the tasks that human EMC experts normally perform. Also, it is capable of analyzing a design before a prototype has been built. And since the expert system does not require the user to be an expert, this analysis can be done at any point in the design process by circuit designers, board layout personnel, or anyone with access to the board layout files.

Finally, the EMC expert system is not a replacement for numerical electromagnetic modeling software. It does not do a thorough analysis of EMI sources with well-defined parameters. However, it excels at the one thing that numerical electromagnetic modeling software does not do well: locating and prioritizing potential EMC problems. Ideally, future printed circuit board designers will have a suite of tools at their disposal. They will use expert system tools to identify EMC sources, antennas and coupling paths; and numerical electromagnetic modeling tools to analyze these structures and evaluate alternatives.