An Expert System Architecture to Detect System-Level Automotive EMC Problems

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Abstract

Improving EMC in automobiles requires methods to detect potential problems early in the design process. Issues involved in the development of a system-level automotive EMC expert system are explored. The proposed system would help identify problems with radiation and immunity, crosstalk, placement of modules, component grounding, and EMC testing. The architecture of the expert system has been developed. The system architecture is designed to allow rapid analysis of automobile designs, to point out potential problems, and to suggest possible solutions.

INTRODUCTION

Electromagnetic compatibility issues are increasingly important to the automotive industry [4]. Problems arise from a lack of flexibility in placement or design of electronic modules and the growing use of high-speed digital and wireless technologies in automobiles. Accurately predicting potential EMC problems and their causes can be extremely difficult, particularly before vehicle design is complete. Because of this difficulty, EMC problems go undetected until a prototype has been built, when it is both expensive and time consuming to rectify these problems.

To help the automotive engineer, an expert system is being developed to predict system-level EMC problems early in the design process. A similar system has been built to predict printed circuit board-level EMC problems and is already being used in industry [1,2,3]. The automotive EMC expert system will use simple rules of thumb, which are experimentally verified, to identify potential EMC problems in the vehicle. Because it must work early in the design cycle, it will be designed to work with incomplete information and still provide useful results. As more information becomes available and as the design matures, the accuracy will increase. The system will be designed to identify potential problems as well as their probable cause and it will be designed to suggest possible design changes to rectify these problems.

Consider the a hypothetical application of the expert system to a new car design. The first application may occur when the precise characteristics of modules are not known. Perhaps the engineer knows the general type of modules that will be used in the vehicle and has worked out their general placement and worked out the routing of wire harnesses. Location of body-surface metal and relative distances between wire harnesses would be approximate. The expert system would calculate radiation or crosstalk using this information and approximate signal levels supplied by the engineer or supplied from a database of acceptable defaults. Results would not be numerically precise because of the uncertainty in the input data, however, the system would be designed such that it would be likely to identify and significant sources of EMC problems. For example, the expert system might estimate a significant amount of noise on the audio feed from the radio. If that noise superceded acceptable levels set by the engineer, the problem would be flagged. Because each noise source is calculated separately using simple models, the expert system might then also identify that the primary source of noise resulted from transients on a windshield wiper motor power line and that those transients are coupled inductively to the audio feed where the two circuits share the same harness. The expert system might then suggest simple strategies for correcting the problem, such as "move the wires to separate harnesses". The engineer could use this information to correct the problem, could analyze the problem more thoroughly using a detailed numerical model, or could wait for additional, more accurate, information. The engineer would run the expert system again and again as the design evolved, checking each refinement for potential EMC problems and taking advantage of improved information.

The basic requirements for an automotive EMC expert system, its proposed architecture, and an outline of algorithms implemented by the system are presented below.

EXPERT SYSTEM DESIGN

The automotive EMC expert system should be designed with specific goals and characteristics in mind. The expert system should help the engineer with wire harness routing, placement of components and antennas, component susceptibility, component grounding, and test plan formation. Because the expert system will be used by both EMC experts and non-experts, it should have the characteristic of being easy to use. It should automatically retrieve information it needs to perform an analysis with minimum input from the user. Because it will be used early in the design process, it should have mechanisms to

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reasonably approximate information it cannot find elsewhere. Because it will be used over and over, perhaps to iteratively test a variety of possible solutions, the system should also be able to perform an analysis in a short period of time. Finally, the system should have an easily modifiable knowledge base so the local expert can add his own rules of thumb or change set points as his understanding of automotive EMC problems improves or the design process evolves.

A characteristic that we do not look for in the expert system is highly precise results. An expert system applies the same rules of thumb and mathematical approximations that an expert would apply in a similar situation. It assists the user by wading through the enormous amount of information available in a design and identifying potential problem areas in a short period of time. Results should be "accurate enough" to identify potential problems. The expert system will not replace the human expert but should allow him to focus his attention only on those areas of need and should allow the non-expert to identify obvious design flaws and possible solutions to those problems. Once the problem is identified, the non-expert can consult the human expert for further advice or the human expert can perform a focused analysis of the problem with more sophisticated (and complicated) numerical tools.

Architecture of the Automotive EMC Expert System

With the overall goals and characteristics of the expert system in mind, an architecture for the system was developed as shown in Figure 1. It consists of 3 basic stages: an input stage, where data is gathered from the outside world; an evaluation stage, which calculates approximate radiation and coupling levels and applies design rules of thumb; and an output stage, which feeds results back to the user. Each stage is composed of several modules. Each module may be further broken into sub-tasks, which are carried out by individual sub-routines. The modular structure of the system makes it easy to modify and test the system and will allow the user to choose which algorithms to use for a particular analysis.

Input Stage

The input stage gathers data from existing databases created through the normal design process, from the user, from an EMC personality file, and from a module library. The majority of information should be automatically gathered from the existing design database to make the user's job as effortless as possible. While the participation required from the user will be minimized, some interaction will be necessary. The user may be asked to enter information the expert system cannot find elsewhere, to enter the location of information, to specify a particular automotive design to analyze, to specify the particular analysis tools that should be used, or to modify the expert system's classification of a particular component or wire. None-the-less, the expert system should be designed such that it can still perform a reasonable analysis if the user is unable or unwilling to provide this information.

In many cases, the design database will not contain specific information about electronic modules necessary for EMC analysis. This information could be contained in a module library. The module library would contain information about each module including signal characteristics, input/output impedance, potential to radiate, potential susceptibility, signal return nodes, power levels, and more.

The EMC personality file will contain design defaults and design rules of thumb created by the local EMC expert. It may also contain information on some unique problems associated with a particular component, so that the expert system can recognize such circuits when they are encountered. The human expert has the option to modify the information or rules in this file to best fit his experience, so the expert system may evolve with the automotive design process.

The raw design data in the local database, the module library, and EMC personality file is prepared for analysis using the circuit classification algorithm. This algorithm identifies "nets" within the vehicle (a net consists of wires and connections that make a continuous conductor – any point on the net is electrically equivalent at DC), assigns characteristics to each net, and identifies the return path (net) that characterize the complete circuit (i.e. pathway from source to load and back). The algorithm will then assign electrical characteristics to each of these nets or circuits. Characteristics assigned to each circuit may include:

- whether the circuit supplies power or is a power return.
- if the net carries a digital or analog signal
- a signal net's load impedance
- the maximum and minimum voltage and/or current
- whether the circuit carries a predominantly continuous or transient type signal
- voltage or current transition times
- the highest and lowest frequencies that occur on an analog net
- potential ability to radiate
- potential susceptibility to noise
- noise margin
- utilization

The classification algorithm will first attempt to find this information from the local design database. If it cannot find the information there, it will search the module library and attempt to assign characteristics to the circuit based on the characteristics of each module. If the expert system cannot find information about a particular module, it will either prompt the user for input or will attempt to infer the information based on connection or naming conventions or

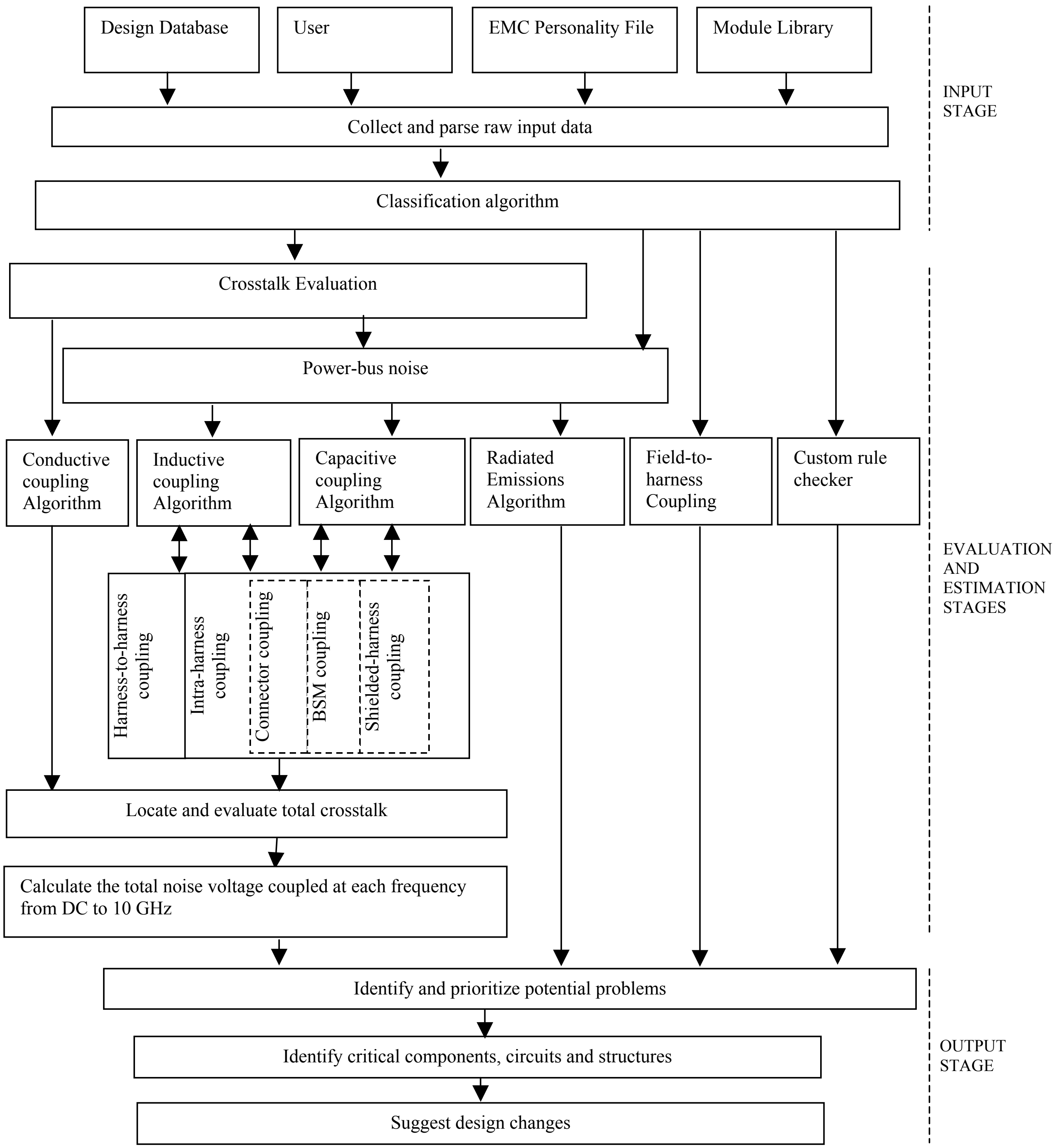


Figure 1: Expert System Architecture

will use a design default provided in the EMC personality file. Since the reliability of information will vary, a confidence factor should be assigned to each characteristic and this confidence should be reflected in the results of an analysis.

After information has been gathered from each source and characteristics assigned to each circuit, the design is ready for the evaluation stage.

Evaluation Stage

The evaluation stage calculates approximate radiation and coupling effects based on circuit and wiring characteristics. Crosstalk is evaluated using a power bus noise algorithm and using algorithms that calculate common-impedance, capacitive, or inductive coupling between circuits. Radiated emissions are calculated with a radiated emissions algorithm. A field-to-harness coupling algorithm calculates noise induced in circuits due to an external radiating source. A design rule checker is used to check basic rules of thumb developed by the local EMC expert. These algorithms are explained in greater detail below.

Common Impedance Coupling Algorithm

The common-impedance algorithm predicts coupling between circuits due to shared impedance along a common return path. For example, in Figure 2, the two circuits share a connector, a length of wire, a grounding lug, and body-surface metal in their return path. The algorithm would search for all circuits that share a common return path and where immunity issues may be a problem. It would calculate the total impedance of the shared return path and then calculate noise coupled across this impedance from one circuit to the other. Modules that place large transients on the return path will be looked at carefully as sources of common-impedance noise. Mutual inductance caused by shared wires will be included. Noise will be calculated in the victim circuit for both transient and continuous wave sources at frequencies from DC to several megahertz. Contributions from each possible source (culprit) would then be combined to estimate the noise induced in a particular victim.

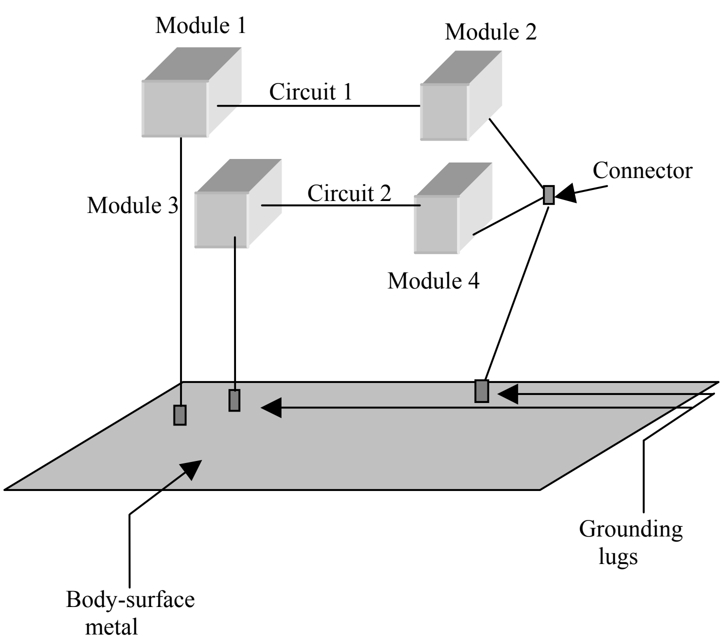
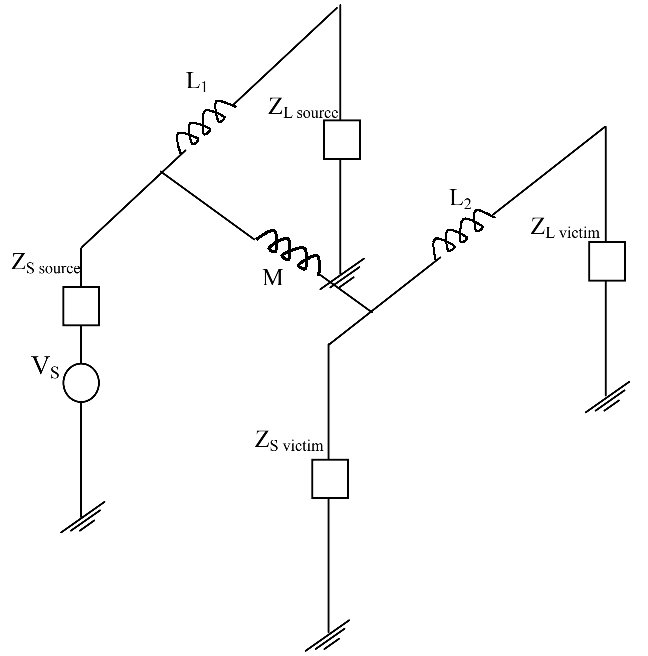


Figure 2: Two circuits sharing a common return path over body-surface metal.



M – Mutual inductance between circuits
$L_{1,2}$ – Self inductance of the circuits
$Z_{S,\,L\ source}$ – Impedances of source circuit
$Z_{S,\,L\ victim}$ – Impedances of victim circuit
V_S – Voltage of source circuit

Figure 3- Inductive coupling of two wires

Inductive Coupling Algorithm

The inductive coupling algorithm calculates the noise induced in one circuit from another due to inductive or magnetic field coupling. It is different from the common impedance-coupling algorithm in that the mutual inductance used to calculate noise does not result from a shared return path but is caused by the relatively close placement of two circuits (Figure 3). The algorithm searches for pairs of circuits that are reasonably close to one another and that might have immunity issues. For such circuits, their mutual inductance, M, can be calculated and used to estimate coupled noise. Inductance can be calculated by splitting the circuit into small segments and calculating mutual inductance between each segment. Mutual inductance should be calculated differently depending on whether the two circuits are in different harnesses (harness-to-harness coupling) or share the same harness (intra-harness coupling) and if the harness is shielded. If the source is continuous-wave, then noise in the victim can be approximated using the formula:

$$V_{Noise} = I_{culprit} \times \omega \times M \times \left[Z_L \big/ (Z_L + Z_S) \right]_{Victim}$$

where V_{NOISE} is the noise induced in the victim, in volts, ω is the angular frequency of the source signal, $I_{culprit}$ is the current flowing in the culprit circuit, and Z_L and Z_S are the load and source impedances of the victim circuit, respectively. If the source is a transient, then noise can be approximated as:

$$V_{Noise} = \frac{\left(I_{culprit} \times M \times \left[Z_L \big/ (Z_L + Z_S) \right]_{Victim} \right)}{t_{fall/rise}}$$

where $t_{rise/fall}$ is the minimum rise or fall time of the source “signal”.

Inductive coupling should be calculated at frequencies from several megahertz to a few gigahertz. Contributions from several sources will be combined for a particular victim. The worse contributors to noise will be tracked so they may be identified later.

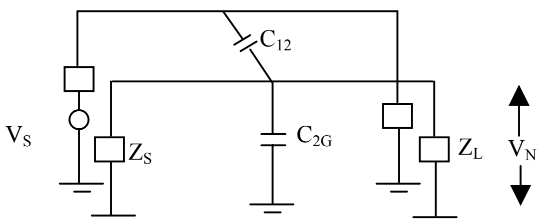


Figure 4: Capacitive coupling of two wires.

Capacitive Coupling Algorithm

This algorithm calculates coupling from one circuit to another due to capacitive or electric-field coupling. The algorithm first identifies pairs of circuits where capacitive coupling may cause immunity problems and then calculates the capacitance between them and to “ground” (Figure 4). Capacitance between the circuits and ground is calculated differently depending on if the circuits share the same harness and if the harness is shielded. As with the inductive coupling algorithm, capacitance between the circuits and ground can be calculated by splitting the circuits into small segments and calculating capacitance for each segment. Noise in the victim circuit can be

$$V_{N(seg)} = \left| \frac{\left[Z_s \| \, 1 \big/ j\omega C_{2G} \, \| Z_L \right] \times V_S}{\left[Z_s \| \, 1 \big/ j\omega C_{2G} \, \| Z_L \right] + 1 \big/ j\omega C_{12}} \right|$$

approximated as:

where Z_s and Z_L are the source and load impedances of the victim circuit, C_{12} is the capacitance between the two circuits, and C_{2G} is the capacitance between the victim’s signal wire and ground. The noise voltage for a transient can be approximated as:

$$V_{N(seg)} = \left| \frac{\left| C_{12} \times (Z_S \| Z_L) \right| \times V_S}{t_{rise/fall}} \right|$$

where $t_{rise/fall}$ is the minimum rise and fall times of the transient signal.

Radiated Emissions and Field-To-Harness Coupling

Coupling between a circuit and an external field is calculated using the radiated emissions and field-to-harness coupling algorithms. Coupling can probably be assumed to originate primarily from the long harness leads in the vehicle. In this case, the gain (ratio of coupled voltage to external field strength) of a circuit might be estimated using transmission line theory. The gain of the system will depend on the circuit’s input impedance, load impedance, and geometry, among other factors. These factors can be calculated from circuit characteristics like the diameter of the wire, the length of the wire, and the average height of the wire over body-surface metal.

Power Bus Noise Algorithm

Most problems due to power bus noise in a vehicle are probably caused by crosstalk or coupling of the noise to an external field (radiated emissions). Automotive components are designed to withstand a great deal of power-bus noise on the power inputs themselves. With this in mind, the power bus noise algorithm should calculate noise on power lines and then pass these noise values to the capacitive coupling, inductive coupling, and radiated emissions algorithms, where they may be used to locate radiation and immunity problems.

Custom Rule Checker

The custom rule checker will be designed to work in tandem with all other algorithms. It will apply custom design rules developed by the local EMC expert.

Output Stage

The output stage processes the results of an evaluation and presents them to the user. It identifies problem areas in the vehicle and lists them by priority. Priority may be set according to the severity of the problem or the confidence in the result. Because the expert system tracks the source of noise or radiated emissions, the user can be told where the likely cause of the problem lies and the expert system can be equipped to give general suggestions as to how the problem might be eliminated. The sophistication of the solutions the expert system can suggest is limited, however, by the complexity of possible solutions. For example, it is reasonable to expect that the expert system could suggest that harness-to-harness coupling could be reduced by moving two wires farther apart, but it may not be reasonable to expect the expert system to suggest specifically where the wires should be moved.

SUMMARY

The automotive EMC expert system should help both the expert and the non-expert detect and eliminate EMC problems early in the design of a vehicle. The system is being designed to require as little input from the user as possible to make it easy to integrate the expert system into the design process. The system will apply simplifying approximations that allow it to identify critical EMC problems and the main contributors to those problems and also allow it to run quickly, giving the user the option to run the system over and over again as he attempts to deal with EMC issues. While results from the expert system will not be precise, they should be accurate enough to identify key problems. The intended capabilities and architecture of the expert system were presented. The architecture is such that the local EMC expert may add design rules or information to improve the utility of the system. Algorithms are under development and will require experimental validation before the system can be built. The final system should help the automotive engineer improve EMC within the vehicle and to produce better vehicles with lower engineering cost and development time.

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