HardSys
Applying Expert System Techniques to Electromagnetic Hardening

Joe LoVetri Electromagnetics Group
Suhayya Abu-Hakima ITS, Lab for Intelligent Systems
Andrew S. Podgorski Electromagnetics Group

DEE, National Research Council, Ottawa, Canada
mail id: suhayya @ nrcvm01.netnorth tel: (613) 993-1268

George I. Costache
Department of Electrical Engineering
University of Ottawa, Canada.

ABSTRACT

This paper describes ongoing work on the application of expert system techniques to the electromagnetic hardening domain.

The domain knowledge is partitioned into four electromagnetic hardening considerations: the ambient field (AF); the shielding effectiveness (SE); the system susceptibility (SS); and the probability of failure (PF). Each of these hardening requirements is implemented as a separate advisor module. Each module can be used independently and each can use information produced by any of the other modules if that information is available and/or required. Such is the case with the probability of failure module which requires the knowledge deduced from the ambient field, the shielding effectiveness and the equipment susceptibility advisors.

A first prototype, *HardSys*, written in prolog and containing a subset of the domain knowledge has been implemented. Preliminary results are encouraging and more work is planned for the system. HardSys will eventually be used to solve real problems as well as be a tutoring aid for persons new to the electromagnetic hardening domain.

1. INTRODUCTION

1.1 The Problem Domain

Many computer aided *analysis* programs have been developed for electromagnetic interaction problems [1]. These programs aid in the calculations of pertinent parameters associated with an electromagnetic model of the problem. This electromagnetic model is usually a mathematical representation of *a subset* of all the physical processes which are taking place in the interaction problem. The real life electromagnetic interaction problem is usually very complex and an exact numerical solution cannot be found to determine the field distributions.

A formal approach to analyzing electromagnetic interactions has been developed by Baum [2]. A discussion on the implementation of these techniques into an expert system is given by Messier [3]. HardSys differs from this in that it does not try to understand the physical topology of the system to be hardened. In other words, the physical relationships between the components of a system to be hardened are not made explicit to HardSys. It is up to the user of HardSys to determine whether there is actual interaction between specific components. HardSys then helps the user to understand the interaction.

Numerical solutions have been obtained for such problems as: electromagnetic penetrations through apertures [4]; coupling between cables [5]; radiation from printed circuit boards [6,7]; and penetration through various shields [8]. These numerical experiments are desirable since they give an insight into relationships between physical parameters and the associated electromagnetic interaction mechanisms. Experts in the electromagnetic hardening domain would have knowledge of many of these interaction mechanisms which would be transformed into useable *rules of thumb* or *heuristics*. These rules of thumb, rather than an exact numerical model, would then be applied to solve a specific electromagnetic hardening problem. This is the model and these are the heuristics which we are attempting to capture in HardSys.

1.2 Expert Systems

In theory [9], an expert system is a computer program which contains, in an appropriate internal representation, some subset of knowledge about a domain of expertise. It can make practical and logical decisions or *intelligent inferences,* to solve domain specific problems with the effect of extending its knowledge.

The obvious advantage of expert system technology is that, unlike human expertise, it can be easily distributed where it is required. Also expert systems can be useful as tutoring aids in that they are usually designed to explain how they arrive at a solution.

2. STRUCTURING THE DOMAIN KNOWLEDGE

HardSys makes recommendations on general electromagnetic interaction problems. To accomplish this we took a high level view of the hardening problem. We decided that the system should reason using the following four general considerations:

i) the ambient field or emitter,
ii) the barrier or shield,
iii) the susceptor or receptor,
iv) and the probability of failure.

These are four considerations which are always present when discussing electromagnetic interaction problems. For example in electromagnetic pulse problems the ambient field may be the field produced via the Compton effect during a nuclear explosion or the field associated with a lightning strike. Alternately, the ambient field of interest may be the one associated with a specific emitter such as a printed circuit board, or it may be the field associated with a certain national susceptibility standard such as Mil-Std-461C. The shield or barrier may be a metallic enclosure with a power-line filter or it may be the packaging of an integrated circuit chip. The susceptor may range from a simple transistor to a whole computer network! The electromagnetic interaction *problem* is the unwanted coupling between the ambient field and the susceptor and is the reason for including a shield.

The above four considerations are always present whether we are talking about inter-system problems (ie. coupling between electronic systems) or intra-system problems (ie. coupling within the components of the same electronic system). The notions of inter-system and intra-system EMI problems are not explicitly represented in the knowledge of HardSys but remain in the mind of the user.

Usually, once the knowledge for the three considerations (the ambient field, the shielding effectiveness, and the system susceptibility) have been determined for a specific problem, it is necessary to determine the probability of failure of the susceptor. If the probability of failure is too great then parameters in one or all of the three must be changed. That is, the ambient field may be reduced if one has control of the emitter, the susceptibility of the receptor may need to be increased, and/or the shielding effectiveness of the barrier can be increased. It is the job of HardSys to recommend an approach to be taken using heuristics and the details of the problem as entered by the user.

This is the framework in which HardSys advises on an interaction problem; defining a consistent standard vocabulary (framework) is the first requirement in structuring any domain of knowledge.

2.1 Ambient Field

The ambient field module presents to the user a list of typical classes of ambient fields. The user may select one of these classes and specify a subclass to get the respective frequency range and the associated ambient field strength. These frequency/field-strength tables are resident in the static HardSys knowledge base. Users may also define their own ambient field. The newly defined ambient field becomes part of the dynamic knowledge for the current session. An example of the ambient field strength table for lightening emission is shown in Figure 2.1.

HardSys uses a frequency domain representation for the ambient field. We define only five qualitative levels: *extreme*; *high*; *medium*; *low*; or *very low;* for the field strength in a specific frequency range. Each level has a numerical field strength range associated with it which the user can request to see. For the ambient field the ranges are shown in Figure 2.2 below.

It is felt that these five levels of classification are sufficient to characterize an ambient field to the level which will be required by the expert system.

The purpose of this module is to help users define the threat associated with their specific ambient field. This is done by a series of questions to which the user enters information. If ambient fields from more than one source are required then a worst case normalization is done by the system in order to determine one characterization which the expert system can work with.

Lightning Emission Levels	
Frequency	**Level**
f < 100 Hz	medium
100 Hz < f < 1 KHz	high
1 KHz < f < 10 MHz	extreme
10 MHz < f < 100 MHz	high
100 MHz < f < 1 GHz	medium
1 GHz < f < 10 GHz	low
10 GHz < f	very-low

Figure 2.1: Sample Ambient Field Data

Ambient Field Level Ranges	
discrete level	**Range**
extreme	> 100 dBV/m
high	40 - 100
medium	0 - 40
low	-60 - 0
very-low	< -60

Figure 2.2: Definition of discrete AF levels

2.2 Shielding Effectiveness

The shielding effectiveness (SE) module helps the user determine the amount of attenuation the ambient field will encounter before the field energy reaches the susceptor. Like the ambient field, this attenuation is also defined with five qualitative levels. These are: *excellent*; *good*; *fair*; *not-good*; or *poor*. The actual numerical value of the attenuation in dB as assumed by HardSys is shown below in Figure 2.3.

The logical flow of this module is as follows. First the user is asked if there is an identifiable shielding barrier present in the system. If the answer is no then the SE is set to poor over all frequency levels. If there is an identifiable shield then HardSys starts by assuming this to be an ideal barrier (ie. SE set to excellent over all frequency ranges). The user is then asked to enter the types of shielding imperfections which are present in the barrier. The types of imperfections handled by HardSys are those shown in Figure 2.4.

2.3 System Susceptibility

The system susceptibility (SS) module helps the user define the susceptibility of the system. This module is similar to the AF module in that the user can either enter a known susceptibility or HardSys can approximate one. This approximation is based on the system technology being used as well as known configuration susceptibilities (such as models of printed circuit board susceptibilities). The SS module contains model susceptibility levels for different technologies commonly used in electronic equipment. If the susceptibility cannot be approximated on this basis, the user is asked to determine it experimentally. A sample susceptibility table available in HardSys is shown below in Figure 2.5. The five levels of susceptibility used by HardSys are shown in Figure 2.6.

2.4 Probability of Failure

The probability of failure module takes results from the above three modules and determines if there is any interaction problem between the ambient field and the susceptor. The probability of failure is reported as being either: *high*; *marginal*; or *low*. In the case where it is high the determining factor which causes such a problem, perhaps an ungasketed seam, may be found by the system so that corrective action can be taken.

Shielding Effectiveness Ranges	
discrete level	**Range**
excellent	> 110 dB
good	75 - 110
fair	25 - 75
not-good	10 - 25
poor	< 10

Figure 2.3: Definition of discrete SE levels

HardSys Barrier Imperfections
a) conductive penetrations b) filtered conductive penetrations c) non-conducting apertures d) gasketed apertures e) special viewing apertures f) special venting/cooling apertures

Figure 2.4: Types of barrier imperfections

CMOS Susceptibility Levels	
Frequency	**Level**
f < 1 GHz	extreme
1 GHz < f < 2 GHz	high
2 GHz < f < 10 GHz	medium
10 GHz < f	low

Figure 2.5: Sample Susceptibility Data

System Susceptibility Level Ranges	
discrete level	**Range**
extreme	< -20 dBm
high	-20 - 0
medium	0 - 20
low	-10 - 10 dBW
very-low	> 10

Figure 2.6: Definition of discrete SS levels

3. IMPLEMENTATION IN PROLOG

A small prototype system has been implemented on a Sun 3/110 in the **Quintus Prolog™** [10] language with the user interface running in an in-house package developed under the windowing/graphics primitives of **NeWS™** [11]. The in-house NeWS interface system is modeled after the **HyperCard™** interface available on the Apple Macintosh personal computer.

A hierarchical illustration of the HardSys advisors is given below in Figure 3.1. The PF advisor is shown below AF, SE, and SS since it requires information from these three advisors before it can deduce a probability of failure for the system. This information is supplied by the advisors in the form of asserted facts to the dynamic Prolog knowledge base. Once a fact is asserted by any of the advisors it is available to all the advisors since there is only one dynamic knowledge base.

Each of the HardSys advisors is implemented as a *stack* of *cards*. The user controls the system by making selections on the cards which are sent as NeWS messages to the Prolog process. The Prolog process services the messages and the user is given relevant information. Help information is supplied to the user via separate cards within the stacks.

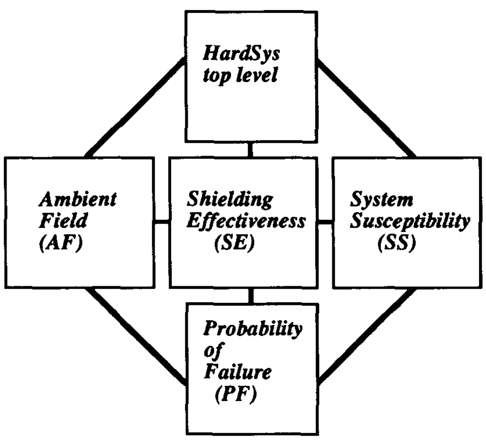

Figure 3.1: HardSys Hierarchy

4. CONCLUSIONS

Preliminary experiments with the system are encouraging; much more knowledge is being gathered for the system so that it may handle more general problems. This knowledge includes additional: ambient field models; equipment and component susceptibilities; as well as models for shield imperfections.

The organization and representation of the knowledge in HardSys is currently being investigated from the point of view of resolving electromagnetic hardening problems using constraint propagation. In addition, numerical modeling algorithms will be interfaced to HardSys to produce custom models required by the user.

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