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CHD: An expert system for the design of cable harnesses

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Abstract

Cable harnesses in systems such as computers, aeroplanes and automobiles are usually the longest parts the major contributors to EMC related problems. However the design of cable harness is an after thought in the design of the whole system. Design of cable harnesses is normally a manual process and does not involve performance study of individual cables. These problems are addressed when the whole system design has been completed by which time the remedy for these problems becomes more difficult. The ability to predict performance of cables at the early design stage would lead to better overall design of the system.

The use of expert systems in other engineering domains has challenged the traditional thinking in the process of cable harness design. A research programme was lunched to investigate the possibility of computerising the process of designing cable harnesses. As a result of this programme, an expert system for Cable Harness Design (CHD) has been developed. This system couples a qualitative analysis of cable harness design and the evaluation of the electrical and mechanical performances of cable harnesses. These two phases of the design have been performed in the Design Rule Checker and Performance Predictor.

1 Introduction

Currently, human experts solve design problems based on experience, specialised knowledge and engineering judgement, using computers for part of the analysis. Expert systems evolved from a long tradition of research that tries

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to simulate the process of reasoning used by human beings. Expert systems were created when the artificial intelligence (AI) scientists turned their attention towards creating an AI programme that would solve a particular problem rather than create programmes to solve any general problems. Expert systems mainly address problems where the knowledge is less deterministic and, as it involves manipulating of symbolic information using heuristics, solutions involving 'rules of thumb' methods can be achieved. Developers have successfully applied AI techniques to some difficult engineering design problems (Pham[1]), but little has been applied to cable harness design.

The design methodology related to cable harness design is a combination of the following three: rule of thumb; 'we did it this way last time', and luck (Rabbit & Morris[4]). The main problems in the design of cable harnesses are clear, they are:

1) lack of formalised and standardised design rules and guidelines;
2) no performance prediction done at the design stage. The selection of cables and connectors is not based on the performance requirements but on what was used in previous designs in the similar equipment;
3) There have not been any commercial software packages available for cable harness design which deals with performance calculations.

2 CHD approach to cable harness design

To address the mentioned problems involved in the cable harness design process, an expert system for Cable Harness Design (CHD) has been developed using the Expert System Builder, CRYSTAL, and it is specifically for cable harness design and analysis. This system has two main components: Design Rule Checker and Performance Predictor. There is a separate knowledge base for each of them, so that they can be maintained independently.

CHD is rule based using combinations of rules, variables and arrays. Logical rule conditions are joined by any combination of IF, AND, OR and NOT. Each rule consists of a sequence of alternatives, each consisting of a conjunctions of alternatives. The alternatives are evaluated in the order they appears, that is conflict is resolved by sequential evaluation. This ordering of alternatives can be changed easily during the building of the system. The rules are the natural way to represent a wide range of practical expertise.

In this rule-based CHD system, the rules contained at the highest level - master rules are:

* Welcome to the system - CHD
* Introduction to the CHD

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* Initialisation of variables
* Main Control Menu
* Design Rule Checker
* Performance Predictor
* Restart or quit the system

In each of the above branch, there are further rules at lower levels. The rules are established in a tree structure.

2.1 Main Components of CHD

Fig.1 illustrates the system's organisational flowchart of the design process. The knowledge bases are the heart of expert systems. CHD consists of two major knowledge bases: one is the Design Rule Checker, and the other is the Performance Predictor.

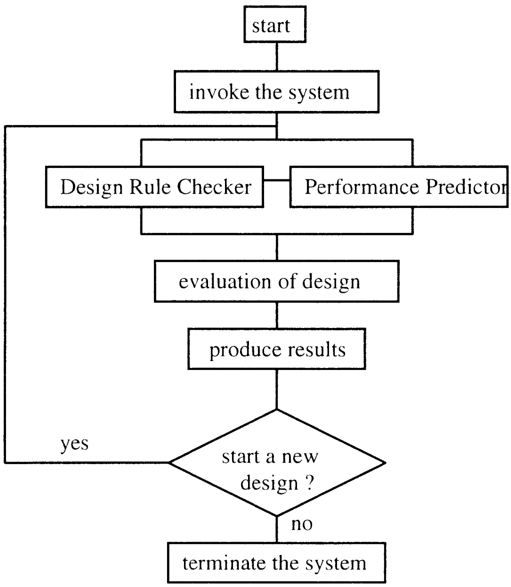

Figure 1. System flowchart of CHD

2.1.1 The Design Rule Checker The Cable Harness Design Rule Checker (CHD-RC) has been developed to formalise the design process. The CHD-RC provides a qualitative rule checking for cables, connectors, harness layout and accessories. The quantitative analysis of reliability and performance of a harness can be invoked by chaining with the Performance Predictor knowledge base when required. The design rules used in the system have followed the IEE Wiring Regulations.

The system simplifies and reduces the time required to develop a cable harness and formalised the design procedure.

2.1.2 Performance Predictor Cable-to-cable coupling produces unwanted signals in a victim cable from a nearby source cable carrying current which results in performance degradation of the harness.

Cable harnesses are normally bent and twisted to fit within the product enclosure. The bending of the harness imposes mechanical stresses on the individual wires which leads to degradation in the performance of the harness.

The Performance Predictor is a quantitative knowledge base designed to predict the potential crosstalk within and between cables. It is also capable of calculating acceptable physical bend levels of a harness.

Prediction of coupling between cables is carried out using computer models. Cable-to-cable coupling models developed are based on the circuit parameters and the concept of 'surface transfer impedance' in the case of coaxial cables (Mohr[3]). The models for both capacitive coupling and inductive coupling in different frequency ranges and for different types of cables have been developed (White[2]).

Dependent on the types of cables present in the harness and the geometric parameters of the harness, the minimum bend radius and the preferred bend radius are calculated.

When CHD analysis has been completed, the suggestions on the design are offered to the designer. The designer can then make modifications to the design. The modified design can be reanalysed to assess the effect of the changes.

After evaluation of the design process and parameters used, especially checking whether the crosstalk ratio exceeds the typical noise immunity level, suggestions will be given to optimise the design on the following aspects: types of wires; common run length; layout of the harness; grounding methods.

3 CHD's Approach to The Design of Cable Harnesses

Unlike traditional CAD systems that capture geometric design information only, the CHD system captures the design intent behind the product design - the "how" and "why" in addition to the "what" of the design. Knowledge about the

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qualitative design and design for manufacturing is captured in the Design Rule Checker; knowledge about whether the cable harness can perform as it should be captured in the Performance Predictor. Using the complete system, Engineers can intelligently evaluate new designs, and optimise the designs using to the suggestions offered by the CHD. The quality of a cable harness designed using CHD is assured as the CHD formalises design procedures.

One of the reasons for employing an expert system to develop CHD is to make the system user friendly. The user does not require detailed knowledge of EMC issues. CHD is designed to be menu driven and offers on-line help.

3.1 Cable Harness Design using CHD

When CHD is invoked, a welcoming screen appears, and it is followed by an introduction to the Design Rule Checker and the Performance Predictor. Then, the user can choose to perform either the Design Rule Checker or Performance Predictor from the Main Control Menu.

In the Design Rule Checker, there are six different options:

1. Design rules for cables
2. Design rules for connectors
3. Design rules for harness layout
4. Manufacturing rules
5. EMC Checklist
6. Quit Design Rule Checker

Dependent on the choice of the user, the system will display the corresponding rules.

Once finished with design rules, the system prompts up the Main Control Menu again, which enables the user to choose another knowledge base - the Performance Predictor.

The sub-menu for Performance Predictor looks like this:

1. Crosstalk analysis
2. Bend radius calculation

or 3. Quit Performance Predictor

Upon selecting the crosstalk analysis, the user is presented with further options as following:

1. coupling between wires/cables
2. coupling in connectors
3. exit from crosstalk checking

Coupling between wires/cables is further grouped into two categories: coupling between single wires, and coupling between coaxial cables. When the required input data is provided, CHD calculates the crosstalk due to capacitive and inductive coupling, and displays the results are displayed. The system then calculates the induced voltage on the victim cable due to the culprit line voltage. For a braided coaxial cable, inductive coupling is normally predominant. However, the dominant coupling type depends on whether the victim circuit impedance is high relative to characteristic impedance. If the both types of couplings exists, the effect of each type is taken into account. The resulting coupling effects are, then, calculated for both near and far ends.

Since among different types of coaxial cables (i.e. braided, semirigid, solid coaxial cables), braided coaxial cables have larger leakage at high frequencies, the research has been concentrated on the performance of braided coaxial cables. The system has incorporated over twenty types of commonly used coaxial cables.

After the system decides the predominant coupling type, the voltage on the victim circuit is calculated, and checks are made to see if the typical noise immunity level is exceeded. If it is, CHD, on request, gives the suggestions on the techniques of reducing the crosstalk and improving the harness's performance.

Once the complete design circle for one set of parameters has been completed, CHD allows the user to change the parameters and go through the design process again.

Typical results obtained from the Performance Predictor are shown in Fig. 2. The figure shows the relationship between crosstalk and frequency maintaining the other parameters constant.

As seen in the graph, due to different transfer impedances (Z_T of RG-58C/U is smaller than Z_T of RG-174), the crosstalk ratios of RG-174 cables are bigger at the whole frequency range.

In order to prove the validity of the models used, experimental work was carried out. Figure 3 shows the comparison of the computed and experimental results. At higher frequencies the experimental results show non linear effects due to resonances. These resonance effects due to the geometrical parameters of the harness are not always controllable. For example, it has been found that the length of the cable in relation to frequencies of the signal determines where in the frequency range the resonance effects are predominant. In particular as the length of the cable increases, the resonance effects occur at a lower

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frequency. Work is being undertaken to incorporate the prediction of the resonance effects within the models.

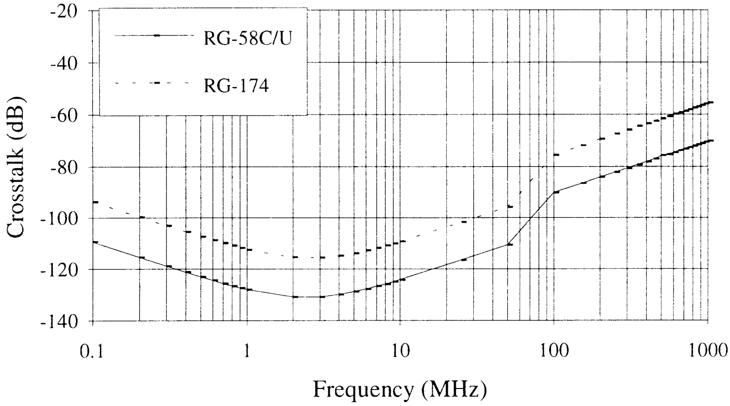

Fig. 2 The relationship between the crosstalk and frequency

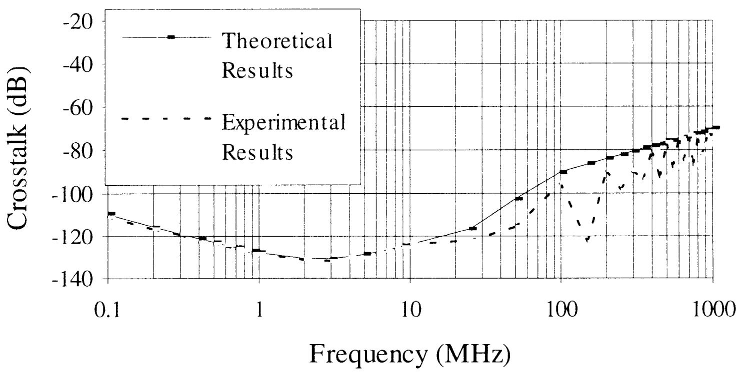

Fig. 3 RG-58C/U, l = 1 m, s = 0 mm, h = 53 mm

When the user chooses to look at the crosstalk within a sub-D connector, the system only calculates capacitive crosstalk for connectors because capacitive coupling is always predominant.

Apart from prediction of coupling levels, Performance Predictor can also perform the prediction of physical bend levels of the harness.

Dependent on types of cables in the harness and the diameters of these cables, the minimum bend radius for the whole bundle is suggested accordingly.

The whole sets of results can not only be seen on the monitor while in the process, but also be sent to a default file.

4 Conclusions

The system CHD has been developed by using techniques of AI. This system differs with other traditional CAD systems in the following aspects:
i) possession of both qualitative analysis and quantitative evaluation;
ii) both Design Rule Checker and Performance Predictor can be used interactively;

These models used in computation have been proved experimentally. Work is continuing to develop models for other types of cables.

In CHD, Design Rule Checker improves the effectiveness and efficiency of the design process, concurrently with Performance Predictor for the computer-aided performance prediction process. It reduces the design specification search time, more importantly, it reduces the dependence on the experts and provides a high quality of information. This expert system could be used to provide both an advisory system for the designer and to allow inexpert designers to produce optimum designs. The inclusion of on line help capability in the system could help the new user understand the system better.

Dependent on whether the user wants to analyse the design problem qualitatively or quantitatively, both Design Rule Checker and Performance Predictor are equipped in CHD, and available to use.

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