USING AN ADDITIONNAL INTERACTION SEQUENCE DIAGRAM TO PERFORM APPROXIMATE MODELLING OF ELECTROMAGNETIC INTERFERENCES AMONG COMPLEX WIRINGS

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ABSTRACT

Electromagnetic topology was introduced in the seventies, with the objective of performing EMC calculations after identification of main interference paths. Thanks to the good shielding approximation it is possible to split the initial problem into several more simple situations, which approximate the actual one. At wiring/ interconnections level, even if the BLT (Baum, Liu, Tesche) equation may be solved in an efficient way, no more simplifications are introduced. For very intricate networks, it is therefore interesting to search for approximate solutions in order to limit the amount of collected data and calculation time. To do so, this paper introduces a new topological graph that possibly enables further simplifications, if a weak coupling approximation is applied. Once this graph is defined, the way it may be used is illustrated. Results are compared with the conventional approach.

INTRODUCTION

The propagation of interferences through wire networks is one of most important research topics in the field of EMC in many industrial environments (car, aeronautic, transport systems, intelligent buildings…) Wiring is a key issue in EMC evaluation, and this weight is being increasing with the high demand in electronics functions together with the application of high level EMC standards. This is typically the case in vehicles: several tens of kilometres of these wires are nowadays present in many of them such as in aircrafts or cars.
ElectroMagnetic Topology (EMT) [1,2] based tools were introduced some years ago to deal with complex cabling networks. They indeed enable versatility and modularity in calculations. Its efficiency was proved in many specific situations for example to deal with non uniform transmission lines or with calculation of electromagnetic field interaction in rather complex situations [3,4].
All these computations are based on an a priori knowledge of positions and electromagnetic characteristics of wires at least with some approximations. Obviously in a real world environment even such an approximate knowledge can not be systematically be recovered from documents or even CAD files. Moreover at early design stages when computation is considered to be useful, it is not cumbersome to deal with number of parameters that are not yet known, such as equivalent input impedances of equipments. In a word, lack of knowledge and uncertainties are an obstacle to carry out direct computations. In many cases, it is thus desirable to limit the number of parameters under investigation before applying any statistic or sensitivity analysis.
However, it is noted that EMT theory which introduces some rather useful approximation at system level where Maxwell 3D codes are used to calculate field distributions, does not introduce any further approximation for cable networks, which are considered as unique topological volumes. To our knowledge, no operating tools have been introduced to break down this unique topological volume into parts. The purpose of this paper is to introduce a strategy for further reducing the inherent complexity of wire networks. To do so, we base our investigations on a new interaction graph, called the Coupling Order Graph (COG) that was introduced in [5]. The COG definition is provided in the first part of this paper. COG paths and related approximations are then discussed. The last part shows a non determinist example of the way the COG is used. It is shown in particular how such a method compares with a conventional approach when performing a sensitivity analysis over some parameters of the network while saving description on non-predominant parameters.

CONVENTIONAL CABLE NETWORK ANALYSIS

In many applications, a TEM-like propagation along wires is considered. Networks are represented by pieces of uniform multiconductor transmission lines that consist in edges (or tubes) of an interaction graph and vertices (or junctions) that interconnect them. Notations for a given piece of multiconductor uniform transmission line are given in Fig.3. Voltages and currents on the transmission line are thus governed by the telegraphs coupled equations that can be identified with the BLT equation :

$$\{[1]-[S][\hat{\Gamma}]\}[W(0)]=[S][W] \qquad (1)$$

For a complex network it represents a heavy task to introduce all required parameters such as the various characteristic impedances, lengths and loading impedances... The order of the BLT system of equations to be solved can in turn become very high. There is therefore an interest in searching for approximate solutions. The following section is devoted to the presentation of an alternative interaction graph which purpose is to reduce the initial complexity of the problem.

THE COUPLING ORDER GRAPH

The Coupling Order Graph (COG) presented below is associated with both the source location and the observation point. Indeed, it is assumed that one is not interested in evaluating the interference level all over the place but only at some specific locations of interest for which for example critical functions have to be carefully looked at.

The COG is an additional topological description strongly associated with the conventional EMT interaction sequence diagram. The use of this graph may be useful for identifying the respective contributions of predominant paths, restricting analysis to these one only. In that sense, it offers an alternative way for calculating interactions once the EMT interaction sequence diagram is established.

The coupling order graph (COG) is defined by the 3 following rules:

Rule 1: Each vertex of the coupling graph represents a physical wire. A physical wire is a wire, which makes a connection between two end impedances. In that sense, it may belong to at least one or more tubes of a conventional EMT interaction sequence diagram.

Rule 2: An edge between two vertices takes place only and only if the two related wires are coupled together on some length in a piece of coupled transmission lines.

Rule 3: The coupling order graph is built up following rules 1 and 2, starting from the wire (or set of wires) on which the source is attached.

A systematic way for building a COG is to start with the EMT sequence diagram. This initial description is obviously the result of an expert analysis. The resulting tube-junction model is considered to be valid at least with a reasonable approximation, so that interactions between any wires in the topological description can be analysed. Our purpose is not to discuss these approximations, but to introduce an alternative analysis instead of directly applying the BLT equation formalism over the entire network.

Let's build up a COG from the example of the interaction sequence diagram of Fig. 1. Tubes are directly represented by their inner wires and junctions let appear connections between wires. Thus, 4 physical wires are identified and labelled from Fig. 1. These are therefore the 4 vertices of the COG. Suppose a source is attached on wire 1. As per Rule 3, wire 1 is the top vertex of the graph. Following Rule 2, the COG associated with the diagram of Fig. 1 is easily built up. The resulting graph appears in Fig. 2. The COG offers a complementary vision of interactions between cables and cannot be substituted to the conventional EMT interaction sequence diagram.

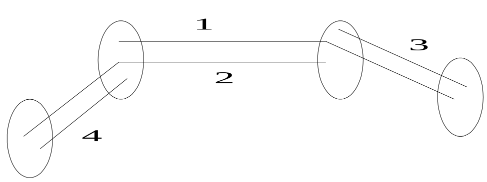

Fig.**1. An example of an EMT interaction sequence diagram**

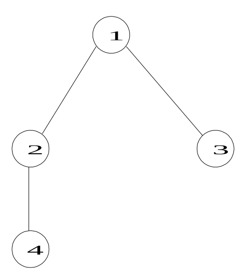

Fig.2 **A Coupling Order Graph associated with the EMT interaction sequence diagram of Fig. 1**

COG PATHS AND COG BASED APPROXIMATIONS

A COG path is defined as a tree graph between the top vertex of the graph and the victim wire under analysis. Given the COG of Fig. 2, suppose we want to calculate currents or voltages at ends of wires 3 and 4. Two paths can be immediately identified for each of these wires : Paths 1→ 3 and 1→2→4. This COG suggests that these

paths may be calculated independently. To do so, we formulate the following hypothesis : The coupled system of wires 1 and 2 can be analysed separately from the coupled system of wires 1 and 3. This implies that the current of the generating line (wire 1) is weakly influenced by the receiving one. This weak coupling approximation is made only with respect to the generating line. This approximation holds in many situations. Its consequences are analysed in section III. Finally, the initial EMT interaction sequence diagram may be separated into two independent diagrams, one involving wires 1 and 2 and the other involving wires 1,3 and 4.
Each possible path between source and victim can be given an associated coupling number, which corresponds to the number of required edges for a path. Applying the weak coupling approximation, paths are restricted to all possible trees between the source and the victim. Thus for the example of Fig. 1 and 2, if the considered victim is wire 4, only the 1→2→4 path is considered. The associated coupling number of this path is 2 and corresponds to the number of coupling patterns the source has followed from the initial attached wire 1 to reach wire 4. Disturbances induced on wire 4 are combinations of derivative functions of the initial source terms, the minimum order of these derivatives being the associated coupling number. Therefore, paths with the lower associated numbers are supposed to be predominant.

COG BASED CALCULATIONS

The following case illustrates the validity and the efficiency of the COG approach when considering a partially undetermined situation. The case considered below is based on the configuration of Fig.3 network. The corresponding coupling order graph is given in Fig.4. End impedances of cable 2 and 4 are considered to be totally unknown. A statistical analysis must be then carried out. This analysis leads to perform many times the same calculations for different sets of random input data. We have performed these calculations using both the conventional method and the COG approach with N=2 (Path2A and Path 2B, see table I))
The range of random impedances (considered in this example as pure resistances) is in between 2 Ohms and 20 kOhms, uniformly distributed on a logarithmic scale. Average and standard deviation evaluation have been performed over 100 calculations. Results for the COG approach are compared to those of the conventional approach (direct solution of the full BLT equation) in Fig. 5. Two curves are provided, one is the average response at wire 3, and the second is the average increased by the standard deviation value.
Results show that the COG approximation is valid. Calculating response of Path 2A and Path 2B in parallel, calculation time is approximately divided by 2 with respect to the classical formulation.

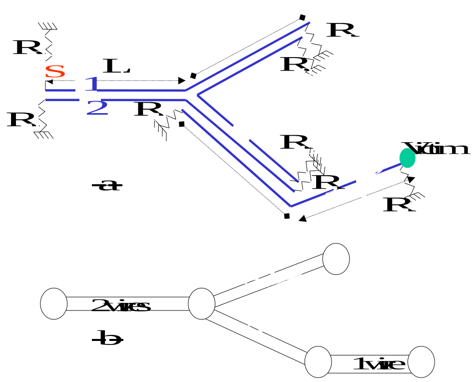

Fig**. 3 Example of a coupled wire network -a- and its equivalent tube/junction representation -b-.**

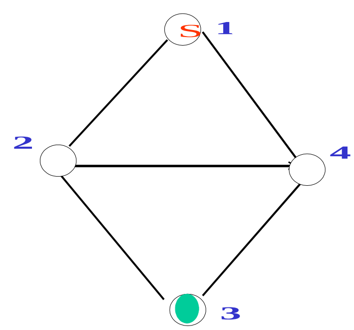

Fig**. 4 Coupling Order Graph associated with the network of Fig. 3**

Table I – Ensemble of paths in Fig. 4 COG.

Name of Path	Associated Coupling Number	Path
2A	2	1→2→3
2B	2	1→4→3
3A	3	1→2→4→3
3B	3	1→4→2→4

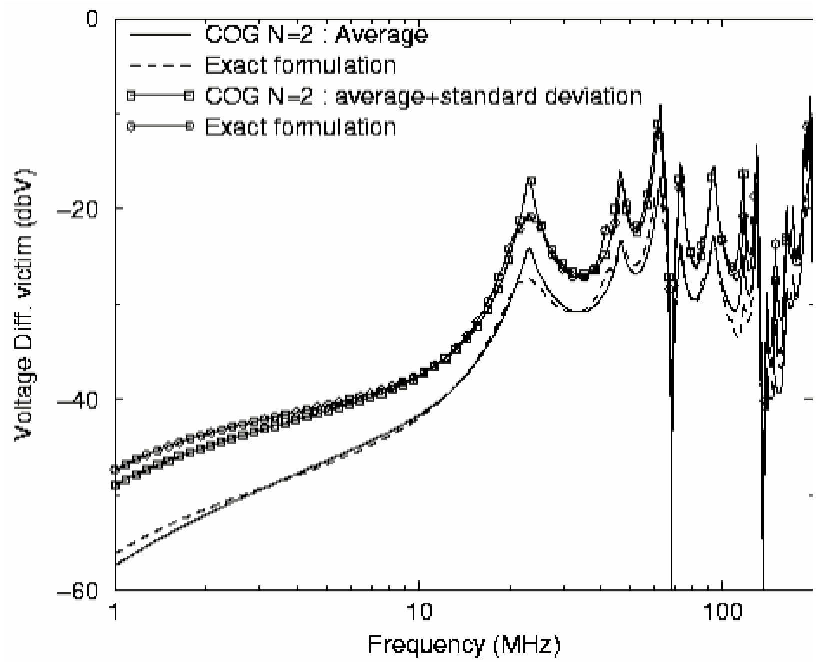

Fig**. 5 Voltage difference at victim's level in a partly undetermined situation evaluated with the COG (N=2) method and with the classical one (exact formulation).**

CONCLUSION

In a conventional approach, large networks require solving BLT equation of order N, with N equals 2 time the number of wires per tube. The COG based formulation of the problem enables to restrict calculation in terms of some parallel paths. Each of these paths is calculated with a classical BLT equation but of much smaller size. Parallel paths may be also calculated in a parallel way. Their contribution may be usefully compared and classified.

To make this possible, a weak coupling approximation has to be introduced. This approximation enables to analyse the COG as a set of tree graphs between the source wire and the victim's one. In many practical situations this approximation holds. However this depends on the accuracy initially required for the model. One of our future works consists in introducing some quantitative criteria based on bundle characteristics and the required accuracy in order to determine whether to apply or not this approximation.

Finally, this new interaction graph opens opportunities to carry out approximate calculations in complex cable networks at a reasonable cost rather than performing a full exact but hardly affordable evaluation.

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