Determination of EM Coupling on an Electrical Wiring Interconnection System

Application of condensation approaches on cable models

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***Abstract*— This paper describes a methodology for modeling of EM coupling on an aircraft Electrical Wiring Interconnection System (EWIS). The challenge is to be able to generate an operatory model taking into account the large number of cables and to maintain a reasonable computation time for the evaluation of the distribution of currents at the interface of equipment pieces. For this, a geometrical condensation approach is implemented and tested on a representative test case at aircraft level.**

***Keywords*— Multiconductor Transmission Line Networks; EMC; EWIS; EM coupling**

I. Introduction

Presently, the more electrical aircraft (MEA) concept leads to an increase of the number of cables which requires developing specific methodologies for modeling external EM radiated field coupling on an Electrical Wiring Interconnection System (EWIS). The methodology proposed here is based on the theory of Multiconductor Transmission Line Networks (MTLN) which is now commonly acknowledged as a very efficient way to handle a large variety of EM coupling situations likely to be encountered on cable harnesses in real systems. The key equation of this theory is the BLT equation in the frequency domain [1]. The BLT equation considers that waves are propagating on the tubes (MTL branches) of the network (combinations of voltages and currents referenced to the characteristic impedance of the MTLs). The equation combines propagation equation on tubes and scattering equations at junctions (which connect tubes) in a single equation. Its resolution provides the various waves propagating everywhere on the tubes of the network. Introducing the wave solutions in either propagation or scattering equations provides the currents and voltages anywhere on the network. However, as far as the entire electrical functions of an aircraft are considered, one difficulty is the size of the resulting MTLN models. Indeed, it is common to encounter topologies with a huge number of branches and with cable-bundle section geometry containing up to 500 cables. To our knowledge, no MTLN tool available at this moment allows the calculation of an entire cable network response at such a level of complexity, especially, with acceptable computation time.

In order to reach one day this objective, ONERA develops a strategy based on its MTLN CRIPTE software aiming at modeling a complex cable harness made of a large amount of wires. The approach combines both simplifications of cable-bundle models [2, 3] and combination of 3D/2D modeling techniques [4]. ONERA has decided to improve, to optimize and to automate all those approaches in order to generate all the input data required for a MTLN model of a cable harness at aircraft level ranging from on-the-shelves cable data bases to cable architecture description (functional links and installation configurations) [5].

Section 2 of this paper presents the description of the methodology. Section 3 presents a condensation approach which has been implemented to reduce the model-size of the branches. Section 4 presents an application on a test-case representative of an aircraft electrical function. Finally, section 5 concludes on the prospects on the relevance of methodology to reach the previously mentioned objectives.

II. Description of the Methodology

A. *Wiring description requirements*

The proposed methodology requires the knowledge of the cable architecture of the aircraft. Two types of inputs must be obtained:

- Inputs on the installation of the wiring inside the aircraft. This includes the knowledge of the routes of the bundle inside the 3D geometry (material nature - geometry – ground plane, raceway…) and geometrical and electrical inputs on local connections of the wiring and equipment boxes to the mechanical ground reference (bonding).
- Inputs on the wiring net list and its constitution in terms of cable types, functional links, functional groups, connectors, shielding. Note that the exact 2D cable cross section is not part of the available data in the industrial process. Actually, this one cannot be made available since the position of the cables inside the bundle is an uncontrolled parameter.

B. *Generation of the MTLN model*

From cable architecture data, a topological analysis can be performed and both definition and identification of the following information can be made:

- Functional links which connect two or more devices together. These links are defined by a function type (signal and end impedance characteristics) and a cable type.
- Functional groups which are a collection of functional links having the same route between two or more devices (equipment or connectors) (Fig. 1). These groups can be also linked to cable-groups (CG) (physical aspect).
- Bundle-segments (BNS) which are an assembly of one or more cables, gathered with a hoop, a sheath or an over-shield (Fig. 1). A bundle-segment has a constant constitution in terms of cables.
- Bundles which are sets of bundle-segments (Fig. 1). Note that no ground reference is taken into account at the bundle description level.

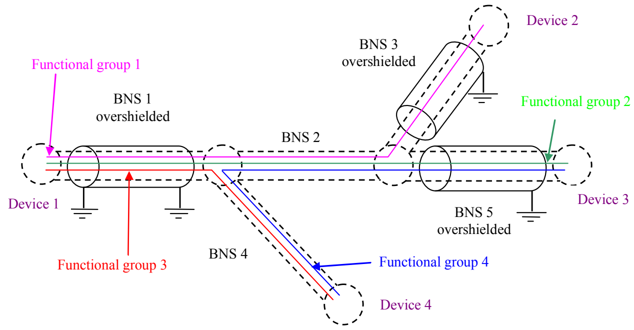

Fig. 1. Example of a cable-bundle configuration and associated terminology

- Tubes which are a geometry assembly of BNSs taking into account a local ground reference (Plane / Shield / Raceway). They are generally described from the information on the installation of the wiring inside the aircraft (3D architecture).
- The nodes which correspond to junctions between two tubes or terminal junctions including input impedances of equipment devices.

From tubes and nodes, equivalent topological network models compliant with MTLN theory (Fig. 2) are generated.

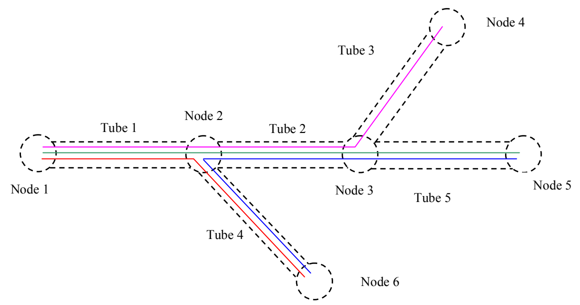

Fig. 2. Topological model related to Fig. 1 configuration

C. Generation of geometrical cross-sections

For each bundle identified in the topological analysis, all cable groups, BNS and tube geometrical cross-sections are generated with the "ALEACAB" tool available in CRIPTE. This generation is performed automatically from the cable-group information (list of functional links and cable types with associated gauges (cable manufacturer data sheet)), the over-shielding information and the installation information (ground reference type (plane, raceway)); the positioning of the cables in the 2D section is then made randomly from this information.

D. Calculation of the p.u.l. [RLGC] matrices

The next step is to calculate the p.u.l. [RLGC] matrices of each tube model. For this, a 2D numerical tool such as the "Laplace" tool available in CRIPTE which allows calculation of the p.u.l. [LC] matrices from a geometrical cross-section description is used. This numerical tool is based on the resolution of the 2D Laplace equation by a method of moment. Note that for simplification we supposed that the conductance [G] is equal to [0] which is a realistic approximation for cables installed at a finite height over the ground reference.

The p.u.l. [R] matrix is built from the knowledge of the characteristics of each wire, of each cable shield or over-shield and the ground common mode resistance (it can be the shield associated to the shielding level if necessary).

In case for which one or many elementary cable(s) or/and cable-group(s) or/and BNS's are over-shielded, the generation of the final assembled MTL per-unit-length (p.u.l) [RLGC] matrices is made sequentially by assembling p.u.l. MTL [RLGC] matrices of each shielding level [6].

E. Description of the excitation source

After having built the MTLN network, this one must be completed by excitation sources. Currently, two source types are considered in our model:

- Local source for signal type (frequency aspect) at equipment level or a Bulk Current Injection test [7].
- If the cable-harness is submitted to a field illumination, distributed sources coming from EM incident fields along the harness routes (tube running location). These radiated EM fields are obtained from 3D calculation and converted in equivalent voltage and current generators with a field to transmission line approach [8].

III. THE CONDENSATION APPRAOCH

This approach aims at a reduction of the size of MTLN models in terms of number of unknowns. It is based on the simplification of the tube models by grouping cables belonging to the same functional groups and making an equivalent wire of each of them. Thus, an approximation operation which transforms each block associated to a cable-group in a scalar as if all the wires were connected together at the extremity of each tube is made. At the end, each p.u.l. [RLGC] matrix of the reduced model is described by a so-called "condensed" matrix of size N×N, N being the number of cable-groups and/or over-shields in the matrix. Note that all junctions (containing connectivity and end impedance information) must be also reduced to have the same order of reduced model.

A few years ago, a matrix condensation technique has been defined and implemented [2, 3]. One of the drawbacks of this approach was the necessity to calculate the total p.u.l [RLGC] matrix before to apply the mathematical transformation which is a main time consumer in the methodology.

The new condensation technique has similarities with [9]: we call it geometrical condensation. It applies a geometrical average on each constitutive material of the cable-group (gauge and diameter of shielded cable, dielectric insulator). The result of this operation is an equivalent wire geometry characterized by:

- The equivalent radius of the metallic core, calculated in summing all surfaces of elementary wires and of shielding of cables.
- The equivalent radius of the dielectric insulator, with the same calculation as the equivalent external radius of cable group.
- The equivalent dielectric permittivity of the dielectric insulator is approximated in summing the each wire surface multiplied by the value of dielectric permittivity and the surface of air (relative dielectric permittivity=1) existing between each wire in the equivalent external radius of the cable group.

Global Geometrical condensation

Fig. 3. Example of a tube cross-section with both approaches (global and geometrical condensation)

Then, the p.u.l. [LC] matrix of each tube is classically calculated with the "LAPLACE" tool. The [R] matrix is calculated with the same method than the first condensation technique [3].

IV. VALIDATION AT AIRCRAFT LEVEL

A. Description of the "aircraft" configuration

Our configuration is based on the implementation of two identical systems: 2 Main Boxes (A&B) and 4 Load Boxes (C to F) and of 13 others identical equipment devices which can be assimilated to electrical hydraulic actuators (EHA1 to 13) because of their location inside the wings and the tail zones. To be more representative in our configuration, some integration constraints (safety) which impose specific routing of functional links have been taken into account (redundancy) (see Fig. 4). Moreover, each cable-harness is routed according to realistic installation rules as for example in a raceway at level of the wings together with segregation rules. The geometrical dimensions of each cable-harness are also representative of a real configuration; for example: 36.5 m between A (cockpit) and EHA12 (tail).

Our choice has been to link equipment items by 9 complex cable-harnesses taking into account 441 functional links grouped in 46 functional groups. All functional links are characterized by a cable type.

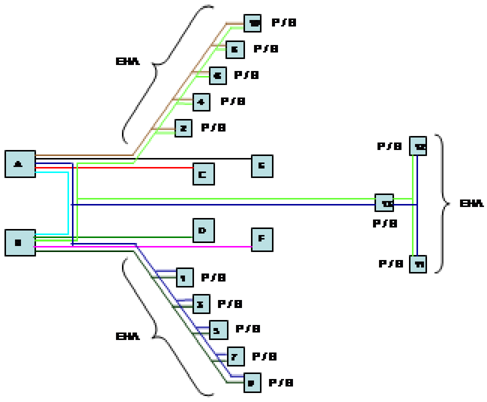

Fig. 4. Description of the aircraft configuration

The aim of this configuration is to demonstrate the capability to calculate a real and complex configuration. Nevertheless we have chosen the following simplification hypotheses which do not refute the realism of the test-case:

- All equipment impedances are short-circuited.
- A calibrated current injection of 1A is applied on two harnesses at the level of EHA9 (extremity of left wing) and the common mode currents on each cable-harness and sub-bundle are observed in the [10 kHz – 400 MHz] frequency band at the level of A&B equipment inputs.

B. Modeling of the configuration

From the functional analysis and installation rules, the CRIPTE topological model can be derived. In our case (Fig. 5), 37 tubes and 40 nodes (junctions) have been used.

The various geometry cross-sections are generated automatically with ONERA's ONECAB tool; the p.u.l. [RLGC] matrices are calculated as described in sections II-D and III. Each end junction is made of a perfect short-circuit and an equivalent constant 100V voltage source is applied to all wires stressed by a BCI-clamp over the whole frequency range at the location of EHA9 (P/S circuits) as described in the section II-E.

C. Results analysis

The aircraft configuration has been modeled by a global approach (full modeling at the level of the cables) and by both condensation approaches (named Matrix and Geometrical in the plot). Note that, for sake of simplification, the elementary shielded cables have been modeled only by their cable shields in the global approach.

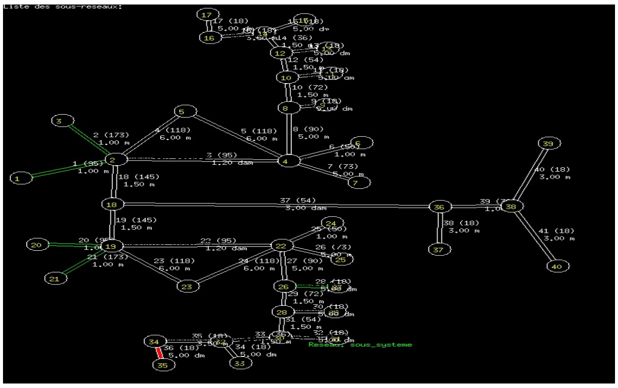

Fig. 5. CRIPTE topological model

One example of comparisons of common-mode currents in cross-talk at equipment interfaces (EHA1P side EHA) is represented in Fig. 6; it shows a good agreement. Firstly, it demonstrates the relevance of both condensation techniques on R, L and C parameters. Note that on the one side the Matrix condensation technique is more accurate but it generates more CPU time on the other side since it requires the total [LC] matrices as input data.

Each step of the calculation process has been evaluated in Tab.1. The time results show that it is possible to predict the distribution of currents on an EWIS in a reasonable computation time. In a pre-design phase, the geometrical condensation technique proves to be efficient and offers the possibility to perform quickly parametric analysis (modification of route…).

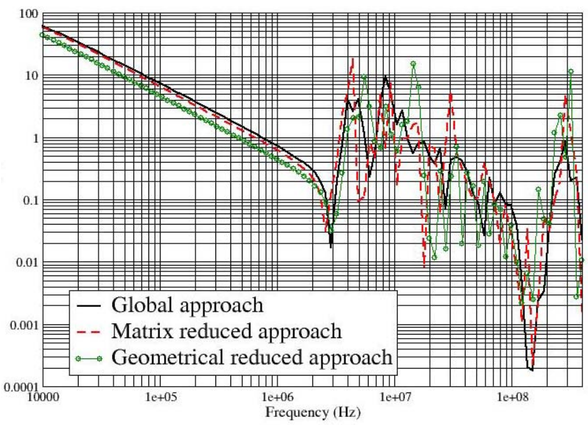

Fig. 6. Simulation results for all approaches (global and simplified) - EHA1P side EHA

V. CONCLUSION

In this paper, the efficiency of our methodology has been demonstrated to calculate quickly and accurately the common mode currents onto a representative configuration of aircraft wiring system. This approach is relevant in a pre-design phase when preliminary evaluation of the response of a complex system in its real aircraft installation is required.

In the future, the following topics have been identified as possible and required improvements in order to obtain more precise results:

- Consideration of wire losses for real wirings composed of strands and losses due to current redistribution in the cable-harness cross-sections.
- Implementation of dielectric losses of the wire jackets for the calculation of the conductance matrix [G].
- Introduction of real impedance of ground planes (distribution in the aircraft internal losses…).

TABLE I. TIME FOR EACH MODELLING PROCESS STEP

Pre-processing : Functional Analysis / batch card of ONECAB tool/ Creation of MTLN model in CRIPTE tool	**3 h**	
Creation of all cross sections (Cable / BNS / Tubes)	**ONECAB tool**	
	3 min	
Calculation of [RLGC] matrices of all tubes (LAPLACE tool)	**Global approach**	**Geometrical condensation**
	7 h	**24 min 11 s**
Matrix condensation technique (time to add to global approach)	**ONECAB tool**	
	30 s	
Creation of all connections at junctions (19 junctions)	**ONECAB tool**	
	15 s	
MTLN calculation for 100 frequencies	**CRIPTE tool (approaches)**	
	Global	**Reduced**
	4 h 22 min	**44 s**

REFERENCES

[1] C.E. Baum, T.K. Liù, and T.E. Tesche, "On the Analysis of General Multiconductor Transmission-Line Networks". Interaction Notes, Note 350, November, 1978.

[2] J.P. Parmantier, I. Junqua, S. Bertuol, F. Issac, S. Guillet, S. Houhou and R. Perraud, "Simplification method for the assessment of the response of a complex cable harness". In Proc of the EMC International, Conference, Zurich, Swiss, January 13-15, 2009.

[3] M. Ridel, J.P. Parmantier, "Equivalent cable-bundle model for large cable response in complex vehicle environment". ESA Workshop on aerospace EMC, Venise, Italy, May 21-23, 2012.

[4] J.P. Parmantier, M. Ridel, S. Bertuol, I. Junqua, C. Giraudon, C. Girard, F. Terrade, J.P. Moreau, "Modeling of HIRF coupling on complex cable architectures", In Proc of the ICEAA'11, Turin, Italiy, September, 2011.

[5] HIRF-SE project, European Community's Seventh Framework Program FP7/2007-2013 under agreement no. 205294, available on at www.hirf-se.eu (accessed 2010).

[6] P. Degauque and A. Zeddam, "Compatibilité électromagnétique – des concepts de base aux applications – In French - Book 1 – Chapter 2, Hermes 2007. In French.

[7] A. Guena, K. Diomande, J.L. Braut, M. Ridel, J.P. Parmantier, J.L. Vagneur and B. Chatellier, « EMC Modeling of Avionic Equipment at low frequency [10kHz – 400MHz]". In Proc of the IEEE International Symposium on EMC Europe, York, England, September, 2011.

[8] S. Arianos, S. Bertuol, M. Bozzetti, A. Francavilla, J.P. Parmantier, L. Pisu, M. Ridel, M. Righero, G. Vecchi, F. Vipiana, "Field to transmission line coupling: a test case within HIRF SE", In Proc of the International Symposium on EMC Europe, Rome, Italy, September, 2012.

[9] G. Andrieu, L. Koné, F. Bocquet, B. Démoulin, J-P. Parmantier, Multiconductor Reduction Technique for Modeling Common Mode Current on Cable Bundles at High Frequency for Automotive Applications. IEEE Trans; on EM Compatibility, vol 50, n°1, Feb: 2000.