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# Field to transmission line coupling: a test case within HIRF SE

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**Abstract** — This paper presents a comprehensive application of the Field-to-TL approach implemented through a computer framework designed to facilitate data exchange among different computational tools. The framework is used also to compare results from different codes, specifically MDD (Multilevel Domain Differentiate) and CRIPTE, thus providing a validation test case for both of them. Furthermore, the comparison with measurements gives an idea of the degree of accuracy obtained with such an operating approach.

**Keywords-component; HIRF SE; Field-to-Transmission-Line; Multiconductor-Transmission-Line Networks; Method of Moments**

## I. INTRODUCTION

This work is carried out in the frame of the HIRF-SE<sup>1</sup> European Project which is focused on the modeling of the Electromagnetic constraints inside an Aircraft submitted to an HIRF (High Intensity Radiated Field) environment for HIRF certification analysis and HIRF compliance system design. This Electromagnetic analysis covers a wide frequency band from 10 kHz to 40 GHz which includes both the conducted and the radiated phenomena.

The HIRF SE project requires a tight interaction between several advanced tools in computational electromagnetic which have been conceived and developed independently from each other. In order to connect the different codes the AMELET standard of EM-model description is used. This standard provides a unique set of parameters for the various types of models required for the exchanges at the interfaces between the computer tools as well as common data formats.

The various tools and scenarios developed in the project have to be validated and compared on specific test-cases. This paper concerns the modeling of EM-coupling on cable harnesses at the level of elementary cables. For this purpose Multiconductor Transmission Line network (MTLN) is now widely acknowledged as an efficient technique to describe a complex wiring topology and the field-to-transmission line (Field-to-TL) scenario [1] as an effective approach to describe

the EM field exciting this wiring. In HIRF-SE, the so-called “GO32” test-case has been designed for the validation of a modeling process involving a 3D MoM solver for the field calculation and a MTLN computer code for the wiring response.

The paper is organized as follows. Section II presents the measurement setup at Alenia Aermacchi’s Open Air Test Site (OATS) in Turin and focuses on the so-called V-inverted antenna configuration. Section III presents the methodology of modeling. In section IV, the 3D model is described. In section V, we present the modeling of the wiring and compare the modeled and measured wiring response. Finally, section VI concludes on future evolutions of this approach in the HIRF-SE project.

## II. MEASUREMENT SETUP

The full validation of our numerical approach consists to reproduce and to compare the simulated results to experimental results. In our case, we have chosen to illuminate a complex harness by several antenna configurations. For this, the experimental features of Alenia Aermacchi’s OATS in Turin have been used.

The actual test case consists to take in consideration:

- a complex harness provided by Piaggio Aero Industries and installed over a table whose surface acts as a metallic ground plane. This one is made of several branches containing shielded and unshielded cables (Fig. 1).

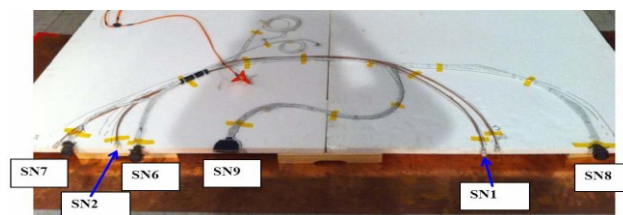


Figure 1. The GO32 cable-harness

<sup>1</sup> The research leading to these results has received funding from the European Community’s Seventh Framework Programme [FP7/2007-2013] under grant agreement no 205294.

- An antenna which is in our first case an Inverted-V antenna. This antenna covers the frequency band [1MHz - 30MHz] in an horizontal polarization (Fig. 2).



Figure 2. In the background, Alenia Aermacchi's inverted-V antenna and, in the foreground, the table supporting the cable harness (Copyright @Alenia Aermacchi)

The calibration of the test area is then performed to obtain an EM field of amplitude 2V/m in the middle of the table (point 0), at 5cm above the table, where the height where cable harness is going to be placed (calibration is performed without the cable harness though). The corresponding RF output power is then measured in the whole frequency range 1÷30 MHz. Actually it turns out, both from measurements and simulations, that the electric field generated by the Inverted-V antenna has a deep minimum along one of the symmetry axis of the table, see Sec. IV and Fig. 3, making a precise calibration with respect to point 0 quite difficult. This problem has been overcome by measuring the E-field also in two other points, respectively at 0.75m and 1.25m from point 0, and actually calibrating the simulations results with respect to the those points (Fig. 4).

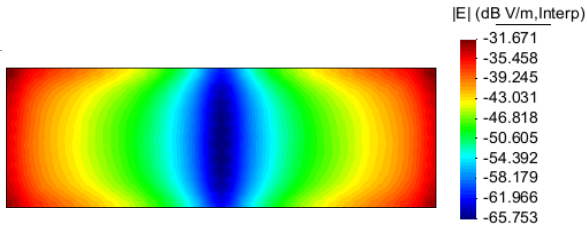


Figure 3. Electric field 5cm above the measure table, @ 10 MHz

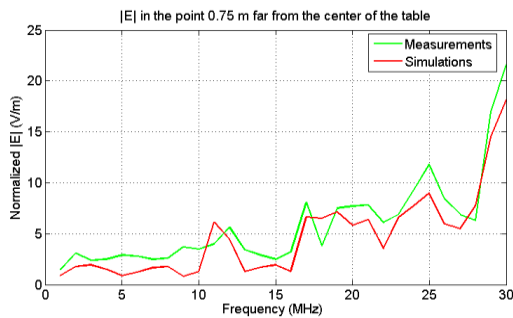


Figure 4. Normalization of simulations w.r.t. measurements

The full test-case (with harness) is positioned and the current values are measured in several configurations at the ends of the cable path (SN1, ..., SN9 in Fig. 1).

### III. MODELLING STRATEGY

#### A. Field-to-TL approach reminder

The field-to-TL theory [1] allows calculating the response of a transmission line submitted to an incident EM field, i.e. the field in the absence of the transmission line. Those incident fields collected along the transmission line path are then transformed as distributed voltage and source models along the TL. Provided that the wiring can be described by a MTLN one can think of using a 3D solver for calculating the incident EM fields. In this case, the path of the wiring on which 3D incident fields have to be calculated is called the “central path” which becomes a part of the 3D mesh or the 3D calculation. For realistic wiring bundles for which the exact position of the cables is not under control, having the same voltage and current generators applied in each cross-section of the MTLN proves to be a practical and reasonable approximation which contributes to the efficiency of the approach.

Such an approach presents several advantages for cooperative numerical scenarios in which parameter approach is investigated on wiring topologies:

- the 3D calculation, generally more resource-requiring than the MTLN calculation is made once for all with any type of 3D solver [2][3], either in time and frequency domains, on all the possible paths of the wiring. The incident fields may be saved for further MTLN calculations.
- since the MTLN models do not depend on the incident field, the MTLN calculation, generally much less resource-requiring can be made quickly on several types of cables topologies including different routes and types of cable bundles.

Several models of field-to-TL are available but the so-called “Agrawal” model is certainly the most efficient model for this type of numerical implementation of HIRF calculation [2]. The two main advantages are the following:

- only one component of the EM field, the incident electric field tangent to the central path, is required for calculating distributed voltage generators (there are no current generators in this model),
- due to the nature of the component of the EM component required, the model does not require any notion of “verticality” (which becomes a problem for real 3D geometry configurations); the EM electric fields just have to be collected along the central path.

#### B. Field-to-TL in a modelling process at system level

The results presented in [2] and [3] demonstrate the capability of the approach. However, in order to integrate this approach in a modeling process at system level, the application of this theory must overcome several difficulties related to the fact that 3D and MTLN models can be generated independently hereafter listed:

- the topological decomposition applied in the 3D model and in the MTLN model of the wiring must be identical
- the EM fields calculated on the central path must be reordered and projected with respect to a unique direction along the tubes. Indeed, due to their own algorithms, 3D mesher tools do not necessarily maintain a logical ordering of the segments.

In order to reach this efficiency, the HIRF-SE project relies on the use of a framework software tool, called CuToo, developed by AxesSim, which proposes an interface for addressing several modeling tools with a common model language called AMELET. For this, each modeling tool uses wrappers in order to communicate and translate its Input/Output native data into or towards the AMELET format. Such organization inside the framework allows implementation of scenarios for exchanging data between families of modeling tools. For example, a typical scenario is the exchange of a 3D geometrical mesh with a 3D full-wave solver. The exchange between a 3D full-wave solver and a MTLN solver is one of the other major identified scenarios for which the framework helps for controlling the generation of data to be exchanged in the modeling process.

C. Field-to-TL procedure on the HIRF-SE test-case

The demonstration carried out in this HIRF SE test case involves 3 main modeling tools:

- CIMNE’s GID solver for the modeling of the geometry of the problem;
- Politecnico di Torino/ISMB’s MDD MoM solver for the calculation of the incident fields along the central path of the wiring network;
- ONERA’s CRIPTE MTLN tool for the edition and the calculation of the response of the wiring to the EM incident fields.

The modeling process is organized in the following steps:

- **Step 1:** building of the topological mode of the wiring. For this, according to CRIPTE’s EM-topology rules, the wiring model is decomposed in tubes and junctions, each tube being a uniform MTL and each junction an equivalent connection circuit. The obtained topological model does not have any excitation source terms yet (Fig. 5).
- **Step 2:** creation of the 3D mesh with organization of the wiring mesh parts in groups, each group being associated to a tube of the wiring topological model.
- **Step 3:** specification of MDD’s input (geometrical mesh and electrical data) and output requests of the 3D solver inside the CuToo framework. In particular, output requests are set at test points all along the wiring central path
- **Step 4:** MDD’s 3D calculation of the electric fields on the output requests along the Central Path. As an output, all the EM fields are organized according to the group definition made at step 2.

- **Step 5:** in the CuToo framework assignment of the EM fields in groups onto the tubes of the topological model made at step 1 and calculation of the MTLN distributed generators with the TOOLMO wrapper which provides appropriate reordering and projection of the electric field along the tubes. As an output, the topological model of the wiring now contains field excitation source terms.
- **Step 6:** CRIPTE calculation of the wiring response with the source terms calculated at step 5.

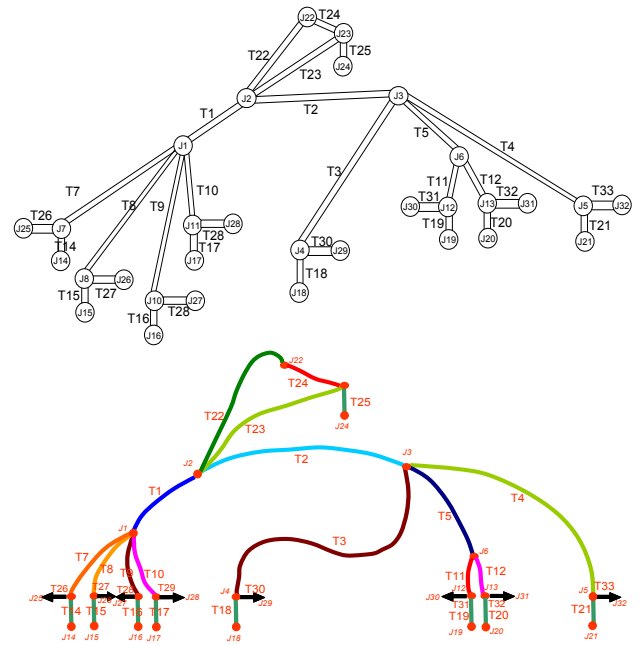


Figure 5. Topological model and associated central path groups on the GO32 test case

In the graph of Fig. 6, the main steps of this calculation process are summarized.

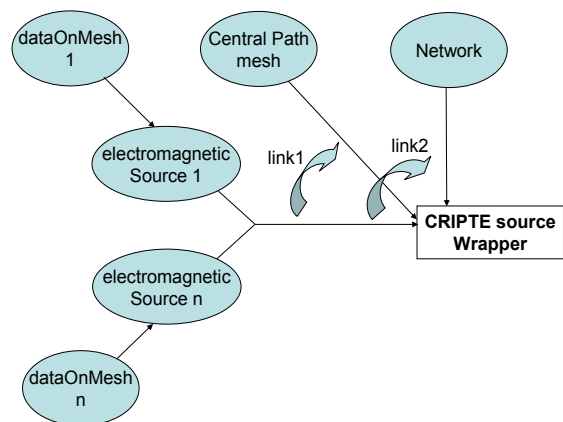


Figure 6. Various input data used by the CRIPTE source wrapper

#### IV. FIELD COMPUTATION SETUP

The full experimental geometry, comprehensive of the Inverted-V antenna, the cable harness, the table and the metallic plates has been designed and meshed using CIMNE's GID software. The electric fields along the cable paths have been computed with MDD (Multilevel Domain Differentiate), a fast multi-scale Method-of-Moments tool developed by the Politecnico di Torino and ISMB [4][5]. These computations have been fully performed within the AxesSim's CuToo computer framework. The output file has then been used as input from ONERA's CRIPTE tool to evaluate the current distribution along the paths, see Sec. V.

The electric field is computed in the middle of each mesh element of the central path, for 30 points in frequency (1-30 MHz). The MDD code provides as output the real and imaginary part of the three components (x, y, z) of the electric field; as mentioned in the previous section, only the horizontal components are used as input to derive the current distribution. In this respect, it is worth stressing that the dominant component of the field generated by the Inverted-V antenna is the vertical one, the horizontal components being at least ten times smaller, in modulus. Furthermore, as mentioned in Sec. II and shown in Fig. 3, this electric field exhibits a pretty large dynamics over the measure table. These factors concur in requiring a high level of accuracy in both simulations and measurements, making the present test case quite challenging from both the computational and experimental point of view. For instance, the role of metallic plates, see Fig. 7, becomes crucial since their presence strongly influences the values of the horizontal components of the nearby EM field.

In order to check the precision of the simulation setup, a configuration with only one cable path (so called "test-wire") has been considered, see Fig. 10. In this case, two distinct quantities have been computed in two specific 3D configurations: the electric field along the cable path (without the wire) and the current distribution along the same path (with the wire). This is feasible because a single cable can be modeled as a thin wire and the current distribution can be fully evaluated within MDD [6]. For the incident field configuration only the metallic plates related to the test wire have been modeled in the geometry.

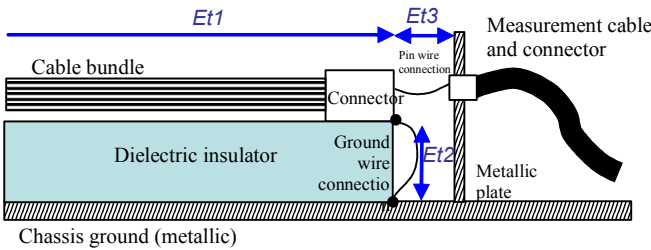


Figure 7. Typical topology of connections at cable ends for which E field has to be collected properly

The current distribution obtained from MDD has then been compared with the one obtained by CRIPTE, using the electric field values from MDD as input. Results are discussed in detail in Sec. V-B.

The configuration with the model of the table and the full cable path is shown in Fig. 8; results are discussed in Sec. V-C.

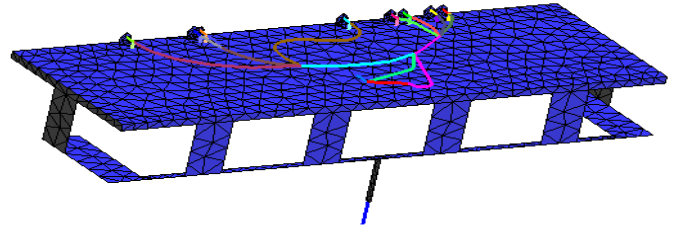


Figure 8. The full simulated setup, cable harness and table

#### V. FROM FIELD TO TL

##### A. Modelling of the wiring

The wiring under study is the complex harness in Fig. 1. Its topology has extensively been characterized and simulated in [7]. This one features eight equipment connectors and nine main branches taking into account 53 functional links (46 unshielded wires (UW), 1 shielded single wire (SSW), 3 shielded twisted pair (STP), 1 shielded twisted triplet (STT) and 2 coaxial cables (CX)) which are grouped into 8 functional groups. All geometrical and electrical characteristics of each elementary cable have been collected from cable manufacturer data sheets.

The first step consists in describing the CRIPTE topological model (Fig. 5) from the analysis of functional links existing between the equipment connector and the test conditions.

The second step consists in describing the geometry cross-section of each tube and in calculating their per unit length (p.u.l.) R, L, G, C matrices. For this purpose, each bundle geometry cross-section is generated automatically and randomly from the analysis of the functional links and from the industrial cable data sheets (see Fig. 9). The p.u.l. R, L, G, C matrices are calculated with a 2D numerical tool applied at each shielding level and the assembling of the various shielding levels. The 2D numerical tool is based on the resolution of the Laplace equation solved by a Method of Moment.

The third step consists in describing the ideal junctions which allow assuring the continuity of each functional link.

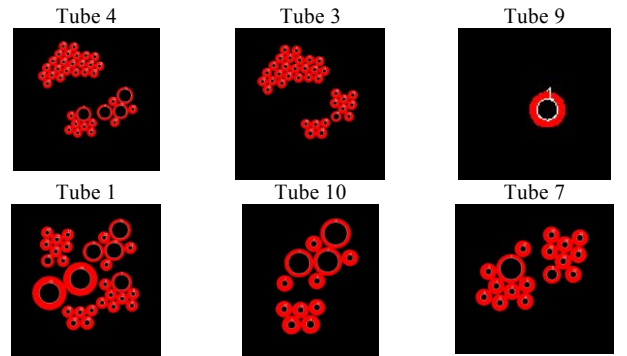


Figure 9. Example of tube geometry cross sections

The next step consists in including the end junctions containing the bonding conditions (shielded cables) at each connector level and the same load conditions as in the experimental tests. In our case, the functional link SN21A22 (UW wire) has been short-circuited (side SN7) and loaded on 50 Ohms (side SN8). The other wires have been put in open-circuit and the shields have been bonded to the table at each extremity.

The last step of the process consists in the resolution of the network equation with the consideration of the source terms calculated previously on each tube. Note that normally all current results are normalized to the calibrated field located at point 0.

### B. Numerical validation on a test-wire

The idea is to compare the results obtained with the Field-to-TL procedure presented before with results obtained using a unique full-wave computer software. The problem is that such a validation requires having a wiring configuration likely to be handled as a whole inside the 3D model (this problem is also the justification of the use of a 3D software and a MTLN code for addressing the real complexity of the wiring). This is why a simplified reference configuration has been extracted on a specific wiring path from ends J14 and J21 in the topology presented in Fig. 3 (see Fig. 10) and by limiting the wiring to a simple test-wire.

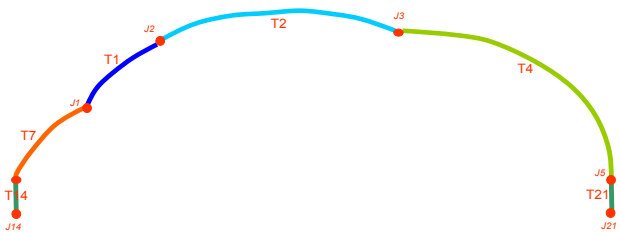


Figure 10. The test-wire central path

The full 3D calculation involving the test-wire and the Field-to-TL approach results are presented in Fig. 11 and show the level of accuracy that can be expected with such an approach. Such results validate at the same time the approach and the TOOLMO wrapper. The validation also demonstrated once more the importance of modeling the vertical parts when applying AGRAWAL's model.

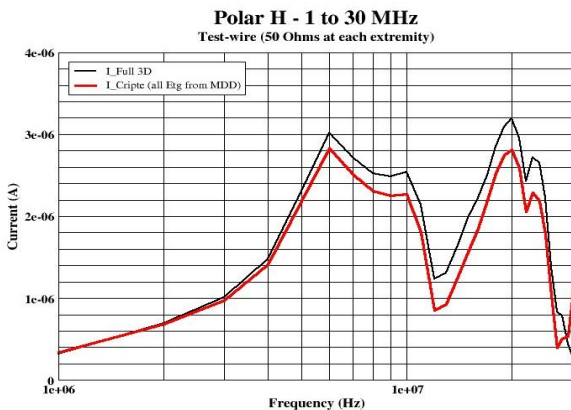


Figure 11. Current along the test wire; MDD vs CRIPTE results

### C. Preliminary experimental validation on the full wiring network

The experimental validation allows validation of the Field-to-TL methodology on the whole complexity of the GO32 wiring network. For this several configurations have been tested and several validation results have been obtained; an example is plotted in Fig. 12. Some difficulties have been observed in the comparison between measurements and calculated results. However those difficulties have to be evaluated at the same level as the complexity of the wiring under study:

- wiring geometry and end connections not fully controlled
- possible tilting in the positioning of the table and its harness with respect to the large V-inverted antenna
- possible calibration and precision issues related discussed in Sections. II and IV (see for instance the resonance-like behavior in the measurements which can hardly be explained and which should not exist between 1 MHz and 4 MHz).

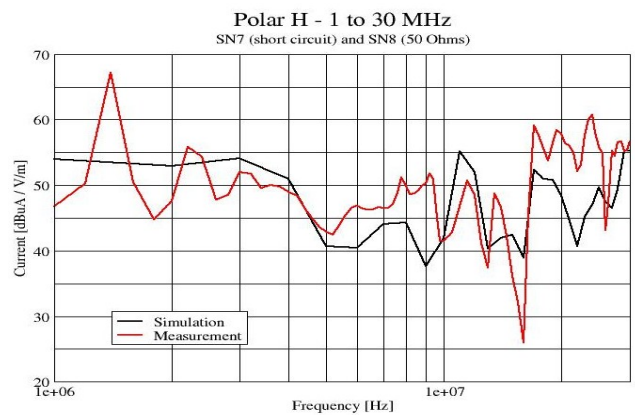


Figure 12. Normalized current (side SN8) with SN8 loaded on 50 Ohms and SN7 in short-circuit

In the next future, a new campaign will take place at Alenia-Aermacchi's OATS in order to consolidate those simulated results. Especially, other antenna configurations will be considered with a monocone (1÷30MHz / vertical polarization) and a log-periodic antenna (30÷400 MHz in both polarizations).

## VI. CONCLUSION

The results obtained in this paper show the interest of the Field-to-TL approach for capturing the complexity of the EM coupling on a real cable bundle installed on a 3D geometry. They also show the interest of a computer framework for the control of the flow of data to be exchanged in a cooperative approach between the three main types of computer tools involved in the application: a 3D mesher for the description of the geometry, a 3D solver for the calculation of the scattered incident fields at the cable bundle level and a MTLN solver for the calculation of the cable response inside the bundle.

As far as more complex wiring topologies are concerned such as the ones encountered in real aircraft or rotorcraft some aspects of the procedure applied here may appear not operating. The main limitations are the topological decomposition of the network in tubes, the modeling of each MTL of the network and the assignment of the distributed incident field sources onto the tubes. In this paper, all those steps have been performed by hand which is not conceivable for an entire wiring system level. This is why AxesSim developed in the HIRF-SE project a modeling tool called CableSim to overcome those difficulties. So far, this computer tool allows automatically building of the topological model based on a description of the whole wiring description including wire types and connectivity inside the 3D geometry (so-called “cable architecture”). Now the tool aims at building automatically the assignment of the 3D sources onto the tubes.

Such a tool will of course help a lot the implementation of the Field-to-TL strategy on complex systems, but it will be based on elementary validated procedures described in this paper.

Finally, remains the question of the representativeness of the MTLN model since it is not conceivable to model the full wiring of an aircraft with such an approach. Simplification rules will have to be applied. In HIRF-SE, an approach in which only a part of the wiring is modeled with MTLN (so called “wiring under test”) and the other part is modeled directly in the 3D model (so-called “environment wiring”) will be evaluated and seems so far a reasonable approach to preserve both the advantages of MTLN solvers for complex wiring EM response and 3D solvers for internal EM field response [8].

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