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Numerical Simulation of Aeronautic Cable Topology and Experimental Validation

M. Ridel¹, P. Savi², M. Alberti³, J-P. Parmantier¹, I.A. Maio², F. Nardone³

Abstract – This paper describes the approach developed in the HIRF-SE EU FP7 project in order to model the topology of a complex aeronautic harness, provided by Piaggio Aero Industries. This approach is based on the CRIPTE modeling software (for Multiconductor Transmission Line Network analysis). To validate the correctness of the model of the topology of the complex harness, S-parameter measurements have been performed and compared to numerical results.

1 INTRODUCTION

This research work is carried out in the frame of the HIRF-SE European project [1] which is focused on the modeling of the EM effects inside an aircraft/rotorcraft submitted to an HIRF (High Intensity Radiated Field) environment for HIRF certification analysis. This Electromagnetic analysis covers a wide frequency band from 10 kHz to 40 GHz, which includes both the conducted and the radiated phenomena. In this paper, we focus on the low-frequency range 30kHz – 400 MHz, in which electrical currents are supposed to be measured according to HIRF-related standards. In this range, the EM coupling between wires (cross-talk) is very important in the prediction of the overall cable system response.

Indeed, electronic subsystems are interconnected by wires which are grouped together into cable bundles. These bundles can have a high degree of complexity since the relative position of the conductors is unknown along the bundle routes. Due to the complex topology, analytical models [2] are not suitable to predict the behavior of these bundles [3].

The aim of this paper is to characterize a real bundle used for avionic application by means of numerical simulation applying the CRIPTE software [4] and S-parameters measurements. The first part of the paper describes the complex harness, the test setup and some test configurations which will be analyzed. The second

part describes the various steps of the modeling of the complex harness in its test configuration with the CRIPTE software. Finally, the last part presents some comparisons between measurements and simulations.

2 TEST CASE DESCRIPTION

The complex harness (HIRF-SE test object called TK6.1 EP09 and TK6.1 EP08) considered in this work is part of the Surveillance Radar System installed in the avionic bay of the Piaggio P166 A/C aircraft.

2.1 Description of the harness

This complex harness features eight equipment connectors, nine branches (see Figure 1) with 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 in 8 cable groups (see Table 1).

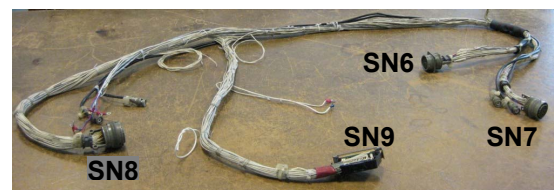


Figure 1: View of the complex harness

For the model implementation, the geometrical and electrical characteristics of each elementary cable have been collected from cable manufacturer data sheets: main requested information concern the wire gauge, the cable sheath characteristics and the physical characteristics of the shields (transfer impedance (magnitude/phase) or simplified Rt/Lt model).

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Connect. 1	Connect. 2	Number by cable type				
		UW	SSW	STP	STT	CX
SN8	SN7	7		1		
SN8	SN6	3		2	1	
SN8	SN9	23				
SN7	SN9	7	1			
J5	PL2013					1
J6	PL2014					1
SN7	SN6	1				
SN6	SN9	5				

Table 1: Definition of each cable group

2.2 Description of the measurement setup

The S-parameters between the conductors of the cable harness have been measured by means of an Agilent ENA 5071B Network Analyzer. The harness has been placed at a distance of 8cm over a metallic ground plane. The dimensions of the ground plane are 160cm x 80cm. Two metallic plates (width 30cm, height 15cm) are fixed on the metallic ground plane. On each plate two SMA connectors are inserted (height from the ground plane 8 cm, distance between the connectors 1.5cm). On one side of the plates the two (four) ports of the NA are connected; on the other side the pins of the wires involved in the measurement are welded to the connector pins (see Figure 2).

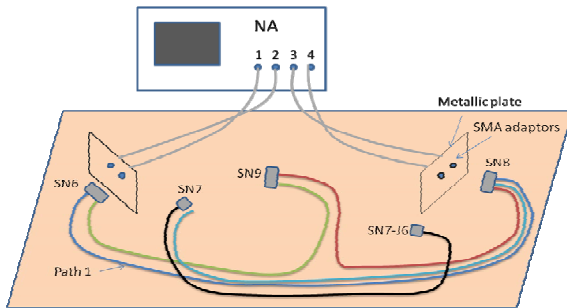


Figure 2: View of the complex harness in its test configuration

Measurements have been performed considering single wires and twisted wires running between connector SN8 and SN6 (total length 195.5cm), and the coaxial cable running from connector J6 to PL2013 (total length 175cm).

2.3 Description of the test configurations

Two types of measurements have been performed: 2-port measurements for the transmission and reflection characterization of a single wire and 4-port measurements considering a single wire and a shielded twisted pair cable for

cross-talk analysis. Here two examples of 4-port are reported.

In the first example, a 2-port measurement on a single wire of the harness, (S7) has been done considering another single wire (S8) as a reference ground (see Figure 3, configuration S7S8).

In the second example, a single wire, S7, and a shielded twisted pair, TW5, with the shields grounded at both ends were considered (see Figure 4, configuration S7TW5). The scattering responses of these configurations are shown in Section 4.



Figure 3: Test configuration of a 4-port measurement on single wires S7 and S8

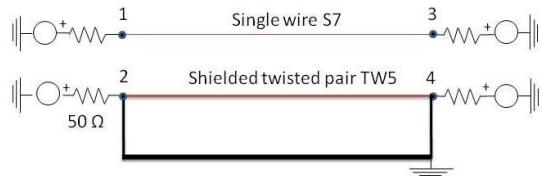


Figure 4: Test configuration of a 4-port measurement on one single wire and one shielded twisted pair

3 MODELING OF THE AERONAUTIC CABLE TOPOLOGY IN ITS TEST SETUP

In this section, each step of the process of the modeling is described.

The first step consists in describing the CRIPTE topological model (see Figure 5) from the analysis of functional links existing between the equipment connectors and the test conditions (see section 2.2). In our case, each branch of the harness is decomposed as a tube. Those ones are connected by ideal junctions that allow assuring the continuity of each functional link and are terminated by terminal junctions which allow applying load conditions (connectors).

The second step consists in describing each tube by per unit length (p.u.l.) R, L, G, C matrices. For this purpose, the bundle geometry cross sections are generated automatically and randomly from the analysis of the functional links (cable groups) and from the industrial cable data sheets (see Figure 6).

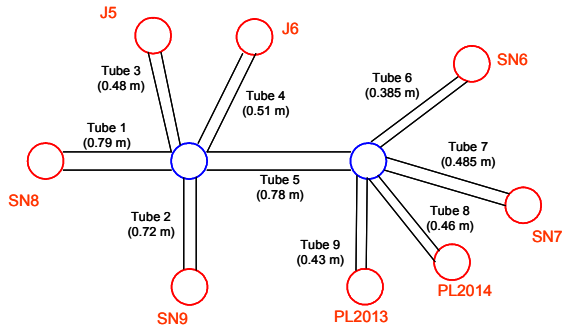


Figure 5: Example of CRIPTE topological model for the TK6.1 EP8/EP9 test-case

The p.u.l. R , L , G , C matrices are calculated and assembled to take into account the various shielding levels generated by cable shields [5].

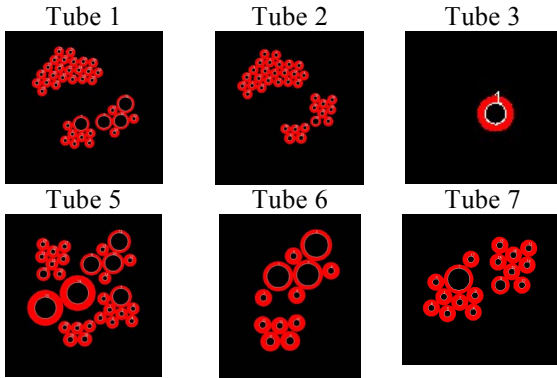


Figure 6: Example of tube geometry cross sections of TK6.1 EP8/EP9 test-case (zoom)

In our case, the transfer impedances of the shields have been measured by NLR, and have been fitted by simple asymptotic behavior with constant transfer resistance, R_t , and constant transfer inductance, L_t . In Figure 7, an example of measured and fitted transfer impedances is plotted.

The third step consists in including the end junctions containing the bonding conditions at each connector level which allow simulation of the same S-parameters conditions than in the experimental tests.

An ideal 1V voltage generator and a perfect 50Ω resistance allow modeling the injection source of the analyzer over the whole frequency range.

The last step consists in the resolution of the network equation with the CRIPTE software which is based on the BLT equation (Baum-Liu-Tesche) [6].

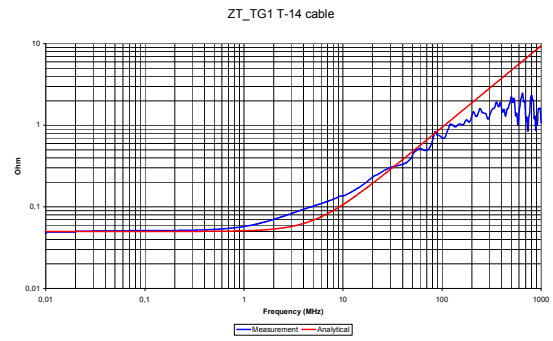


Figure 7: Transfer impedance of the SSW (Measurement by NLR): $R_t=0.05\Omega$ and $L=1.5nH$

4 COMPARISON MEASUREMENTS / SIMULATION

This section presents the comparisons between simulation results and measurements.

Figure 8 and Figure 9 show respectively the comparison between four S-parameter simulations and measurements for the configurations “S7S8” and “S7TW501”.

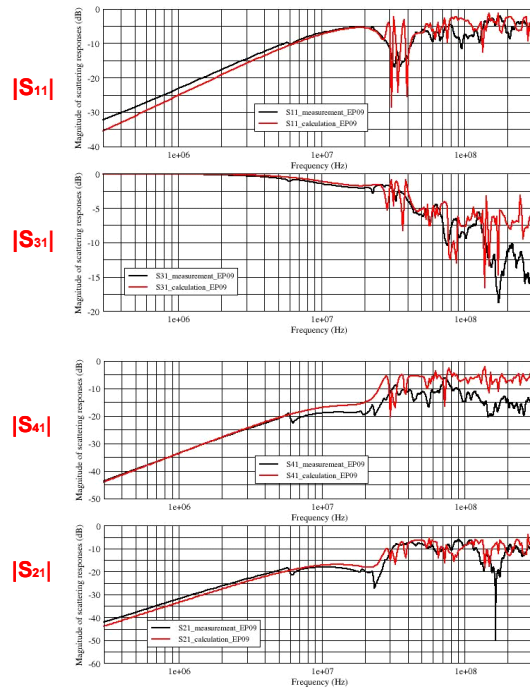


Figure 8: Scattering response of a two single wire (configuration S7S8 of Figure 3) considering an input signal at port 1. From top to bottom: S_{11} , S_{31} , S_{41} and S_{21}

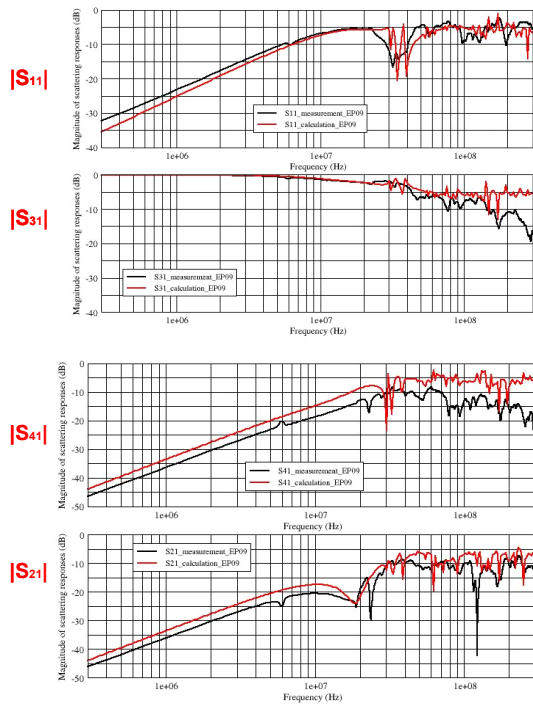


Figure 9: Scattering response of a single wire and a shielded twisted pair cable (configuration S7TW5 of Fig.4) considering in input signal at port 1". From top to bottom: S_{11} , S_{31} , S_{41} and S_{21}

At low frequency, the good agreement observed on all the plots also proof that the connectivity of the whole network at branch and connector levels has been correctly modeled. At higher frequencies, in the resonance regime, better agreement could have been obtained if all spurious electrical elements due to test-set-up (contact resistance, bonding resistance and inductance) had systematically been taken into account. In addition the modeling results do not show the attenuation observed on several measurements which could mean that a frequency dependence of wires losses should have been introduced.

As far as coupling on the shielded cable is concerned, a simple fitting with a transfer resistance and a transfer inductance of the shield was sufficient in order to obtain satisfactory results.

The results also show that the random generation of the cable bundle 2D cross-section geometry allowed phenomena good reproduction of the measured cross-coupling results.

4 CONCLUSION

In this paper, the modelling of a real harness has been demonstrated. The whole modelling process included the fact that the real geometry was loosely controlled and was therefore

considered as representative of situations occurring in real avionic applications

Based on the knowledge of available information stored in electrical data bases or aircraft data bases, it was possible to build a MTLN simulation model of this complex harness applying reasonable but operating approximations. However, we have to underline the fact that transfer impedance data are not generally available in such data base whereas their knowledge is absolutely required for shielded cable response assessment.

In the continuation of the HIRF-SE project, this model will be used in a near future for determining the cable harness current and voltage responses when this one will be submitted to a common mode EM field illumination.

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