Optimization of Three-dimensional TEM cell for Electromagnetic Compatibility Testing

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Abstract: This paper illustrates the possibilities offered by WIPL-D code to characterize the electromagnetic behaviour of Electromagnetic Compatibility (EMC) test facilities and to determine their optimal design. The test facility considered in this paper is the three-dimensional TEM cell, which was patented by INRETS in 2000. This paper aims to highlight the advantages of using WIPL-D code in the different development steps of this new test facility. The precision of the results given by WIPL-D code will be examined through experimental and numeric comparisons.

Keywords: EMC, Three-Dimensional TEM cells, S-parameters, electric field

1. Introduction

Three-Dimensional TEM cells (3D TEM) are new electromagnetic test facilities to characterize the immunity and the radiation of electronic equipments in the lower frequencies [1]. The optimization of the first prototype was performed through experimental, theoretical and numerical approaches. The paper presents the optimization steps based on using the WIPL-D code and highlights the advantages of combining experimental and theoretical approaches with a numerical method.

After a description of the 3D TEM cell prototype and a background of its functioning principle, we present the WIPL-D model carried out in order to validate the numerical approach. The numerical results are compared with experimental results in order to indicate the accuracy of the tool. The following section deals with the using of the model to define the optimal dimensions of the strip lines into the cell. This section highlights the advantages of combining theoretical and numerical approaches. The last section describes the numerical method employed in order to improve the uniformity of the electric field into the 3D TEM cell. We observe in particular the accuracy of the results in terms of field distribution and the real interest of the numerical approach due to the field measurements requiring excessive times.

2. Description and functioning of the Three-Dimensional TEM cell

The EMC tests applied in the lower frequencies exploit the electromagnetic properties of the TEM cells. TEM cells are metallic cavities including an unique horizontal strip line. Knowing that equipment under test (EUT) must be tested according to three orthogonal polarisation coupling planes, measurements performed in conventional TEM cells require placing successively the EUT in three different orthogonal positions in relation to the unique strip line of the cavity.

Three-Dimensional TEM cells were created to include at least three plates placed in two-by-two orthogonal positions in order to avoid modifying the orientation of EUT and to reduce the testing time. The 3D TEM cell prototype studied in this paper included two groups of three two-by-two orthogonal plates. This prototype can be used in a balanced mode that can be very beneficial in term of repeatability and useful test volume. The balanced prototype developed, represented in figure 1, is a 1-meter cubic cell and presents a total symmetry according to the three x, y and z-axes.

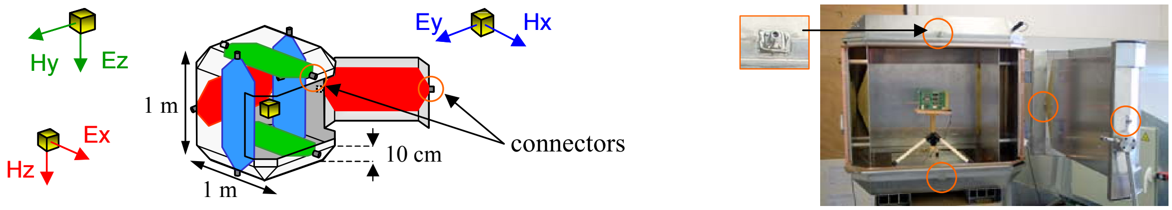

Fig. 1. 6-plate 3D TEM cells

Radiation tests consist of placing the EUT in functioning at the center of the cell, as represented in figure 1, and successively collecting the voltages induced at each connector. The total radiated power of the EUT is then calculated from these voltages. The radiation spectrum can be obtained in measuring only the voltages appearing on three orthogonal plates. However, by applying a testing methodology based on the use of six plates instead of three, we reduce the probability of the results depending on the orientation of the EUT inside the cell.

For immunity testing, the EUT is also placed at the center while the different ports are successively fed in order to illuminate the EUT with three orthogonal polarisations of electromagnetic field. Theoretically, only three plates are necessary. Nevertheless, to guaranty the validity of the test, for each polarisation of field, the EUT must be immerged in a homogeneous field in terms of magnitude and polarisation. The volume of homogeneous field into the cell defines the test volume. Knowing that the gradient of the electric field can be reduced in the inner volume of the cell by feeding the two-by-two opposite plates, the useful test volume can be extended by employing a 6-plate structure.

Thus, the optimization of the 3D TEM cell consists in dimensioning and adequately feeding the plates in order to increase the higher useful frequency limit by improving the impedance matching at the ports of the cell and, to extend the useful test volume by increasing the homogeneity of field.

3. Elaboration and validation of the simulation model

In order to employ a numerical approach to optimize the design of the plates in the prototype, the first step is to validate a WIPL-D simulation model of the empty cavity. A simulation model (figure 2) was carried out without the plates and without taking into account the dissymmetry introduced by the presence of the door. Simulations and experimentations were performed including two 22 cm-length monopole antennas, as represented in figure 2. The transmission and reflection S-parameters between the two monopole antennas was collected experimentally and numerically. For the experimental approach, two crossing cavity connectors were inserted at the two antennas bases. The S-parameters were measured by connecting a network analyzer to these two connectors. Measurements were performed with a 0.5 MHz frequency step and simulation with a 1.5 MHz frequency step. The numerical and experimental transmission S12 parameters between 200 MHz and 900 MHz are compared in figure 3.

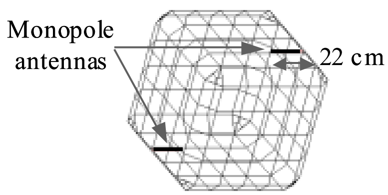

Fig. 2. Empty cavity simulation model

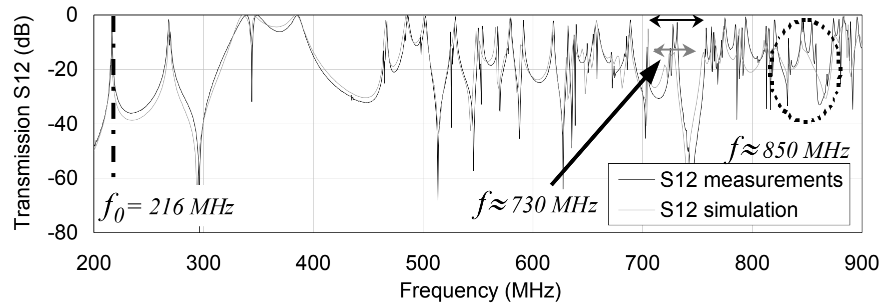

Fig. 3. Numerical and experimental transmission S12-parameters

Measurements and simulation results present a good agreement with the exception of a few differences in the higher frequencies. The differences mainly concern the maximum levels (ex: 230 MHz on the figure) or the number of maxima (ex: ≈ 850 MHz on the figure). Knowing that the mode density of the cavity increases in the higher frequencies, the simulation frequency step is probably too large to detect all the maxima. Moreover, the real model can be imperfect in terms of conductivity and dimensions. These imperfections impact all the more the results since the wavelength decreases.

These curves show the impact of the first resonance frequency of the cavity on the S12 parameters at 216 MHz [2]. This frequency constitutes the maximal frequency of using the TEM properties and exploiting the 3D TEM cell for EMC testing. Thus, the optimization concerns only the frequencies inferior to the first resonance frequency. Due to differences appearing above 600 MHz only, the accuracy of the simulation results is sufficient in relation to the objective.

The six plates must be dimensioned in order to obtain a good impedance matching under the first resonance frequency, between the transmission line constituted by the cell and the measurements equipments, which must to be connected to the ports of the cell. For this, the characteristic impedance of the transmission line that constitutes the cell and its plates, must to be 50 Ω. One way of knowing the quality of the impedance matching is to observe the level of reflections at the ports.

Six plates were adjusted in the simulation model and generators were localised at their extremities as represented in figure 4, to observe the reflection S-parameter. Figure 5 shows that 1 cm-cables were placed between the extremities of the plates and the wall. The generators were based on these cables, which are also present in the prototype in order to connect the plates to the connectors.

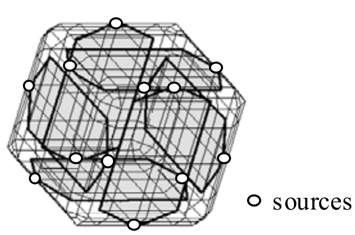

Fig. 4. The 6-plate simulation model

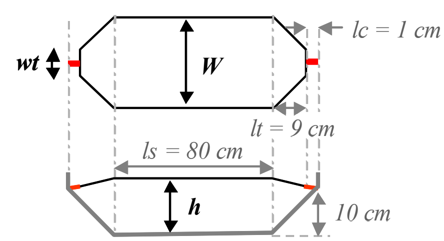

Fig. 5. Geometry of the plates

S-parameters simulations were carried out with different values for the widths ***W*** and ***wt*** and the distance ***h*** between the plates and the wall (fig. 5). Among the results obtained, we conserved the dimensions giving a level of reflection inferior to –20 dB on the larger frequency band [3]. These dimensions (***W*** = 53 cm, ***wt*** = 9 cm and ***h*** = 10 cm) were applied to the plates included in the prototype in order to compare experimental and numerical results. Figure 6 presents the Sii-parameters and one of the coupling Sij-parameters.

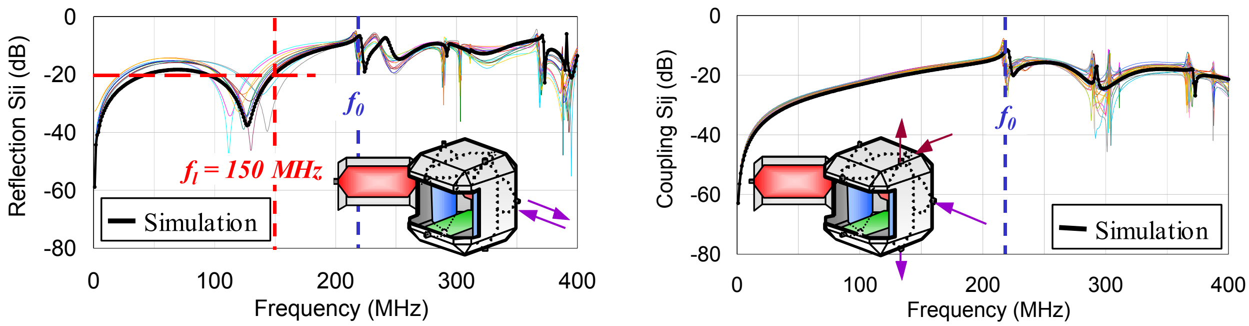

Fig. 6. Numerical and experimental S-parameters

On each graph, only one simulated S-parameter is represented due to the twelve extremities of the simulation model being perfectly identical. On the contrary, the experimental results present some differences between the reflection S-parameters measured at the different ports. These differences illustrate the imperfections of the prototype. However, the agreement obtained is very satisfying and demonstrates that the simulation model can be an efficient tool to optimize the dimensions.
The results show that the reflection coefficient is inferior to – 20 dB up to $\boldsymbol{f_l}$ = 150 MHz and above this frequency it increases strongly up to the first resonance frequency $\boldsymbol{f_0}$. The objective is to increase the frequency $\boldsymbol{f_l}$ when the reflection coefficient reaches – 20 dB. Consequently, we developed a theoretical approach in order to understand the impact of the different parameters and to establish a rule of building for 3D TEM cells. The simulation model was employed to validate the theoretical approach and to define the values of the neglected parameters in the theoretical approach.

4. Optimization of the dimensions of the plates

The structure was studied as if it was a coaxial transmission line, considering that one of the plates is the interior conductor of the line and the other plates are parts of the exterior conductor [4]. Then, the problem was assimilated to the study of an infinite rectangular coaxial transmission line of which the impedance characteristic $\boldsymbol{Z_0}$ is in function of the capacitance of the line $\boldsymbol{C_0}$ and of the velocity $\boldsymbol{v}$ (1).

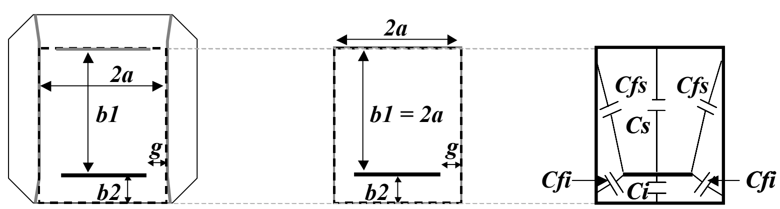

Fig. 7. Cross section studied in the theoretical approach

$$Z_0 = \frac{1}{v\,C_0} = \frac{377}{Cs + Ci + 2\,Cf_s + 2\,Cf_i} \cong \frac{377}{\left[\dfrac{2W}{b1} + \dfrac{2W}{b2} + 2\,\dfrac{2}{\pi}\ln\left(1+\coth\dfrac{\pi\,g}{2\,b1}\right) + 2\,\dfrac{2}{\pi}\ln\left(1+\coth\dfrac{\pi\,g}{2\,b2}\right)\right]} \qquad (1)$$

The parallel and fringing capacities which composed the capacitance of the line (1) were expressed in function of the dimensions of the cross section. The characteristic impedance expression (1) obtained permitted us to determine adequate dimensions (***W= 47 cm***, ***b2 = 11 cm***) to have $\boldsymbol{Z_0}$ = 50 Ω and the theoretical approach was validated by simulation. On figure 8, the simulation results obtained with these new dimensions are compared to these obtained with the first model (figure 6).

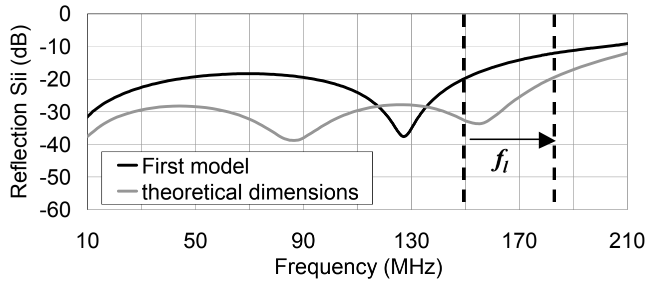

Fig. 8. Numerical reflection S-parameters obtained with the dimensions determined from the theoretical approach

The results demonstrate the validity of the theoretical approach due to the limit frequency f_l, where the reflections reach – 20 dB being increased of 30 MHz. However, the width of the plate ***wt*** at the extremities cannot be defined by this approach which considers only the cross section. We then used the simulation model, which is a very efficient tool when only one parameter varies, to determine ***wt***.

5. Characterisation of the electric field distribution into the 3D TEM cell

The second step consists of extending the useful volume of test for immunity testing. Firstly, we characterized the distribution of electric field in feeding only one plate with 1 Watt at 75 MHz and we compared measurements and simulation results. Electric field measurements require large amount of time due to the field probe (figure 9) only giving the characteristics of the field at its location. Moreover, to obtain a good agreement between simulation and measurements, precautions must be taken. In particular, in injecting 1 Watt with a generator, the power which arrives on the plate can be lightly different as a result of the losses in the cables and in the connection. We then placed a combiner at the extremity of the fed plate in order to control the injected power with a wattmeter (figure 10).

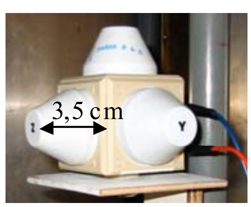

Fig.9. Electric field probe

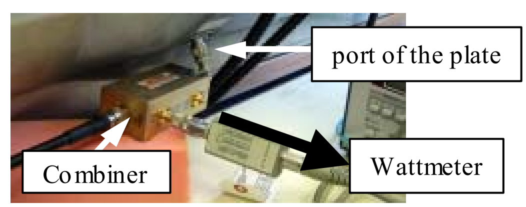

Fig. 10. Protocol of power control

We compared the electric field obtained by simulation and experimentation on different points of the cell. As represented in figure 11, we displaced the probe along the x and z-axes in the cell and we measured the Ez field component.

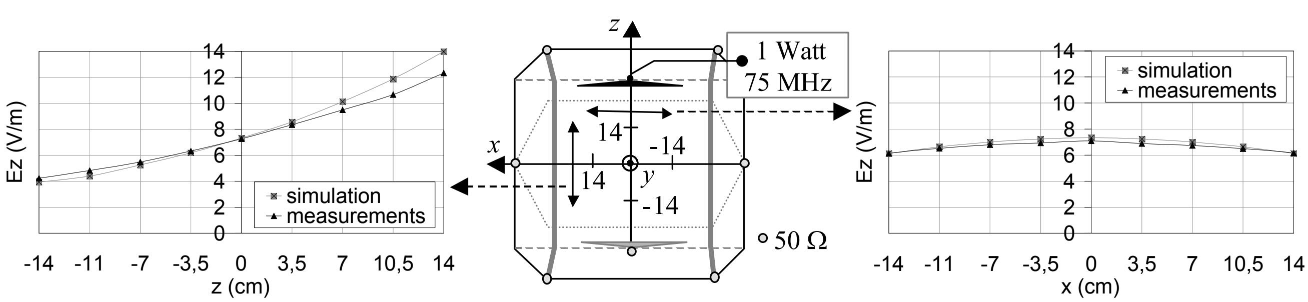

Fig. 8. Numerical an experimental values of the Ez component along the x and z-axes

With the exception of a few differences at 14 cm on the z-axe, the agreement is very satisfying. Moreover, the differences are not surprising because the simulation gives the values of the field at a precise location whereas the experimentation gives a value corresponding to the field which acts on the 3.5 cm-length axe of the probe. Due to the excellent accuracy and the simulation permitting us to obtain the distribution of the field very quickly, we completely defined the optimal configuration alimentation of the plates by using only the simulation. We came to the conclusion that by simultaneously feeding two opposite plates in 180° phase difference, we can conserve a variation of the Ez component inferior to 2 dB in a 24 x 24 x 24 cm^3 centred volume (Fig. 9).

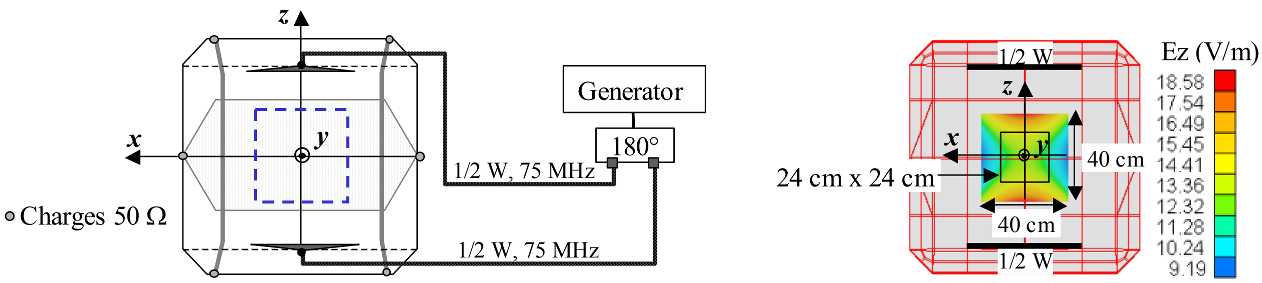

Fig. 9. Numerical distribution of the Ez component in the (x, z) plane

6. Conclusion

This paper which presented an example of numerical application for optimize the using of a test facilities showed that WIPL-D code is particularity well adapted to metallic structures of modesty dimensions (1m^3). By simultaneously employing theoretical and numerical approaches, the impedance matching of the 3D TEM cell could be strongly improved. The comparisons between numerical and experimental results showed that the accuracy of the WIPL-D code can be very satisfying if precautions are taken in the acquisition of experimental results. Generally, the differences observed between numerical and experimental results do not come from the WIPL-D code but from the frequency step, the experimental protocol or the imperfections of the real structure. However, through a good understanding of the numerical and experimental manipulations performed, the disagreements can easily be explained and the numerical code constitutes an efficient tool.

References

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