Radiated Power Measurements of Electronic Equipments in Three-Dimensional TEM Cells

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Abstract –Three-dimensional TEM cells are new test facilities which permit us to measure the total radiated power of equipment under test, in the lower frequencies, without having to place it in different positions. Firstly, this paper briefly presents the three-dimensional concept and the optimisation works carried out to improve the impedance matching of the plates. Then, after a summary on the experimental approaches used for radiation measurements in TEM and 3-D TEM cells, radiation measurements results of an off-the-shelf electronic equipment performed in both test facilities are compared in order to study the reproductibility and the repeatability of the results. The final section of this paper focuses on the useful test volume of the 3-D TEM prototype.

1. INTRODUCTION

Among the test facilities used today to characterise electronic equipments and systems, TEM cells are the only known test facilities that cover the low frequency band. However, in all variants of such TEM cells, the full three-dimensional characterization of equipment under test (EUT) can only be obtained by rotating it. Three-Dimensional TEM (3-D TEM) cells [1] were therefore developed in order to regroup the electromagnetic properties of three conventional TEM cells into one to avoid moving the EUT. Moreover, by decreasing the size of the cell, this tool may be extended to radiation measurements of electronic components working on large frequency range. However, this paper only focuses on electronic equipments tests.

2. THE THREE-DIMENSIONAL CONCEPT

Knowing that, in the lower frequencies an EUT must be characterized according to three orthogonal coupling planes, measurements performed in conventional TEM cells require placing the EUT in three different orthogonal positions regarding to the unique strip line of the cavity. Originally [1], Three-Dimensional TEM cells were therefore created to include three plates placed in three different orthogonal positions in order to generate three orthogonal components of electric and magnetic fields. However, by including three additional plates opposite the first three plates, we can use the prototype in a balanced mode that can be very beneficial in term of repeatability and useful test volume. On the one hand, for radiation measurements, we reduce the probability that the total radiated power obtained depends on the position of the EUT by collecting the voltages appearing at twelve ports instead of six ports. On the other hand, for immunity testing, we can reduce the gradient of the components of the electric field in the inner volume of the cell by feeding in phase the two-by-two opposite plates by half the input power. This could allow us to increase the useful test volume.

The prototype developed, represented in figures 1 and 2, is a 1-meter cubic cell. It permits us to have symmetrical situations according to the three x, y and z-axes.

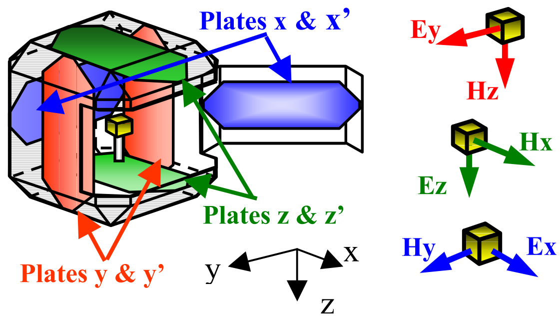

Fig. 1: 6-plate 3-D TEM cells

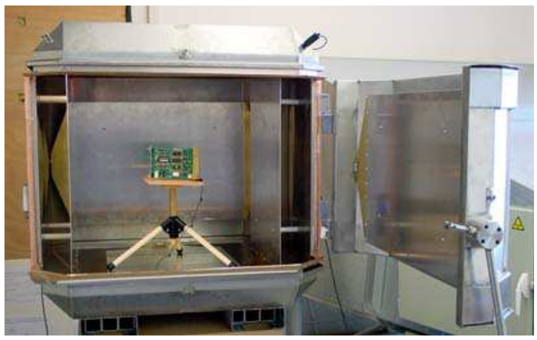

Fig. 2: The 6-plate 3D-TEM cell industrial prototype

3. IMPEDANCE MATCHING OF THE PLATES

The first resonance frequency of the considered cavity appears at 215 MHz. Consequently, above 200 MHz, the TEM functioning is not maintained due to the resonance's appearance. We therefore tried to improve the impedance matching of the plates up to 215 MHz in order to increase the transmission of power from the power source to the interior of the cavity.

Contrary to conventional TEM cells, in 3-D TEM cells the plates can not be symmetrically placed inside the cavity, and the rules used to determine the appropriate dimensions of the strip line giving a characteristic impedance of 50 Ω in a conventional TEM cell, cannot be exploited. We then developed a generic analytical optimisation method [2] for an asymmetrical structure, allowing us to determine the adequate dimensions of the plates according to the cavity's geometry.

Firstly, inspired by the approach to conventional TEM cells [3], we obtained a characteristic impedance relation in function with the dimensions of the prototype cross section (Figure 3).

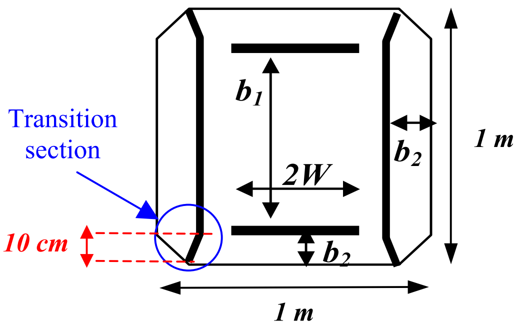

Fig. 3: 6-plate 3D-TEM cell's cross section

The relation (1) permitted us to determine couples of values (***W***, $\boldsymbol{b_2}$) for the width of the plate and the gap between the plates and the walls giving a characteristic impedance of ***50 Ω***.

$$Z_c \cong \frac{376.62}{\left[\frac{2W}{b1}+\frac{2W}{b2}+2\frac{2}{\pi}\ln\left(1+\coth\frac{\pi g}{2b1}\right)+2\frac{2}{\pi}\ln\left(1+\coth\frac{\pi g}{2b2}\right)\right]} \qquad (1)$$

Then, to define the best couple of values, we calculated the appropriate slope for the transition section of the plates to conserve a constant ratio between the dimensions of the upper and the inferior parts of the cross section to the current flowing along the plate [4]. Due to the length of the transition section being imposed at ***10 cm***, the slope of the transition imposed a unique $\boldsymbol{b_2}$ value and the ***W*** associated value to get a characteristic impedance of ***50 Ω***.

To illustrate the results, figure 4 presents reflection S-parameters obtained at the extremity of one of the plates between 10 MHz and 210 MHz. We only considered the frequencies inferior to 210 MHz due to the inevitable increase of the reflection coefficient resulting from the appearance of the first resonance.

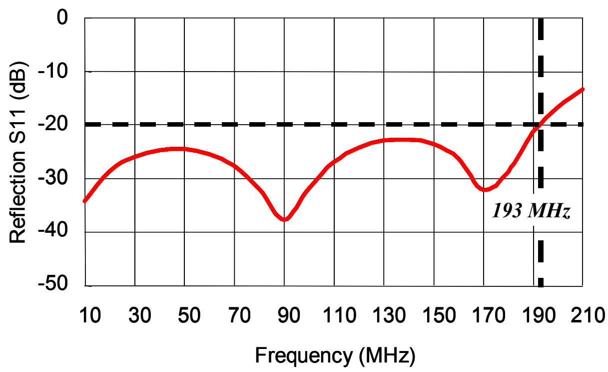

Fig. 4: Reflection S-parameters at one of the connectors

However, this figure shows that the reflection coefficient stays inferior to -20 dB up to 193 MHz. Keeping in mind that the first resonance frequency is 215 MHz, this result is perfectly satisfying.
As a reference, we measured the reflection S-parameters at each port of a standard AR TC3020A TEM cell which works up 375 MHz. These results are presented in figure 5.

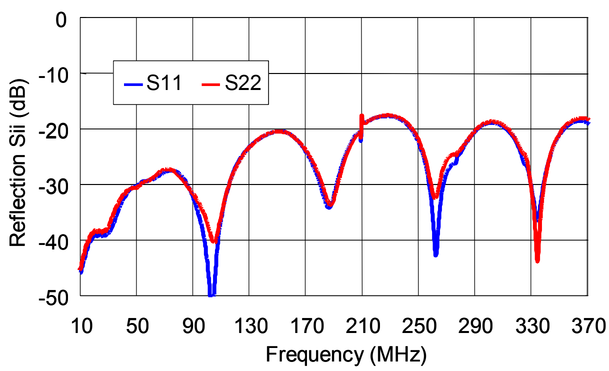

Fig. 5: Reflection S-parameters at each ports of a conventional TEM cell

Knowing that this TEM cell can be used up to 375 MHz, we represented the reflection S-parameters obtained for the frequency band 10 MHz - 370 MHz. Regarding the levels of reflection in figures 4 and 5, we can see that the analytical method developed allows us to obtain, on an asymmetrical structure, an impedance matching as good as that of a conventional TEM cell.

4. RADIATED POWER MEASUREMENTS

In order to measure total radiated power in TEM cells, the EUT needs to be placed according to three orthogonal orientations as represented in figure 6 [2].

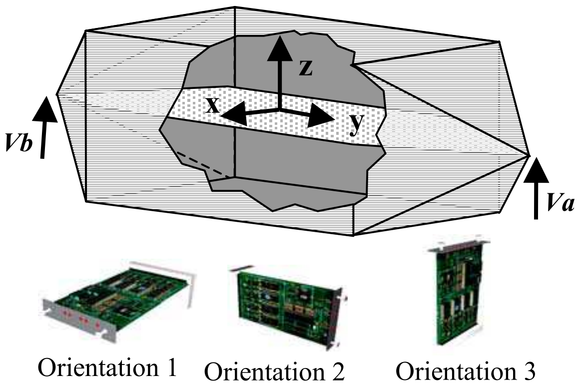

Fig. 6: Experimental approach in TEM Cell

For each position in which the EUT is placed, voltages ***Va*** and ***Vb*** are measured with a spectrum analyser at both ports of the TEM cell. The total power radiated is then obtained by using the relation (2):

$$Pt = \frac{2\pi Z_0}{\lambda^2 Z_c e_0^2} \cdot \frac{1}{3} \cdot \sum_{i=1}^{3} (V_{ai} + V_{bi}) \qquad (2)$$

Where V_{ai} and V_{bi} are the voltages measured at both ports for the three orientations in Volts, e_0 is the normalized electric field for an input power of 1 Watt in the TEM cell and Z_c is the characteristic impedance of the cell.

In the case of the measurement performed in the 3-D TEM cell, it is not necessary to change the position of the EUT and the total radiated power is given by (3):

$$Pt = \frac{2\pi Z_0}{\lambda^2 Z_c e_0^2} \cdot \frac{1}{6} \cdot \sum_{i=1}^{6} (V_{ai} + V_{bi}) \qquad (3)$$

Where V_{ai} and V_{bi} are the voltages measured at both ports of the six plates in Volts.

We carried out a comparison of total radiated power measured in both test facilities. For each test facility, three series of tests were performed in order to observe the measurements repeatability. In the TEM cell the three tests were identical and in the 3-D TEM cell, we modified the orientation of the EUT between the three tests in order to verify that the measurements results did not depend on the position. Moreover, the EUT mainly radiating between 50 MHz and 100 MHz, we only considered the results obtained in this frequency band.

Firstly, we calculated the average results of the three series of tests performed in each test facility. The averages total radiated power collected in both cells are presented in figure 7. The blue curve represents the average of the three results collected in the 3-D TEM cell and the red curve illustrates the average of the three results obtained in the TEM cell.

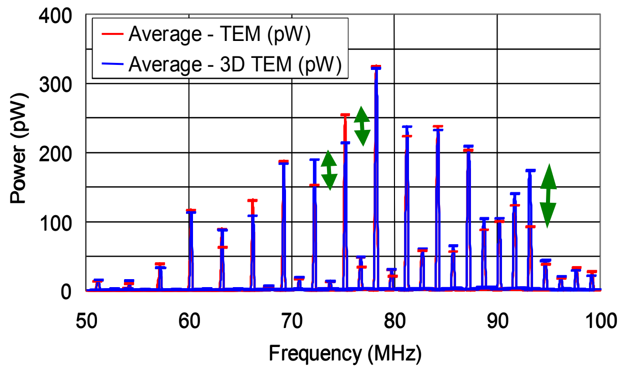

Fig. 7: Average of three results collected in both cells

Figure 8 shows a relatively good agreement between the two average results of the tests performed in both cells, except for some differences appearing at certain frequencies (see arrows).

5. REPEATABILITY RESULTS

In order to observe the repeatability of the measurements carried out in both cells, we have presented the results of the three series of tests for the TEM and the 3-D TEM cells in figures 8 and 9.

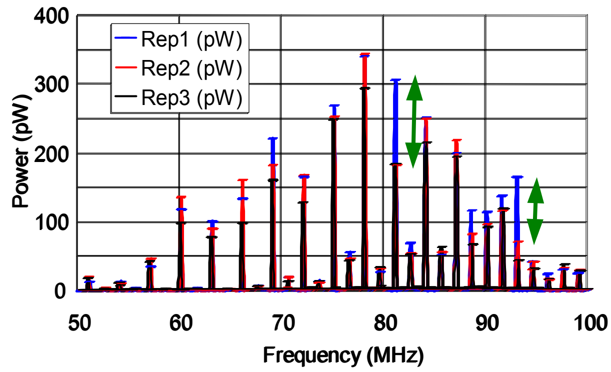

Fig. 8: Total radiated power collected in TEM cell

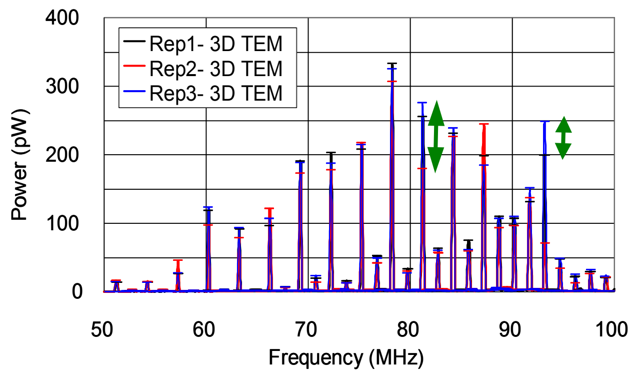

Fig. 9: Total radiated power collected in 3-D TEM cell

Through these results, we can see some problems of repeatability regarding the differences appearing between the three results of tests performed in each cell. Effectively, we see some significant differences at certain frequencies between the three results for each test facility. However, we also see that the greater differences, which are highlighted by arrows in the figures, appear at the same frequencies in the results obtained with the conventional TEM cell and the 3-D TEM prototype.

6. USEFULL TEST VOLUME

In the case of the 3-D TEM cell, the space between a plate and the opposite wall is greater than in a conventional TEM cell due to the strip line not being centred. Consequently, the gradient of the electromagnetic field in the centre of the cavity is relatively strong if only one plate is fed [5]. Figure 10 represents an example of the simulated total electric field distribution created by the plate X in the yz-plane for an input power of 1 Watt.

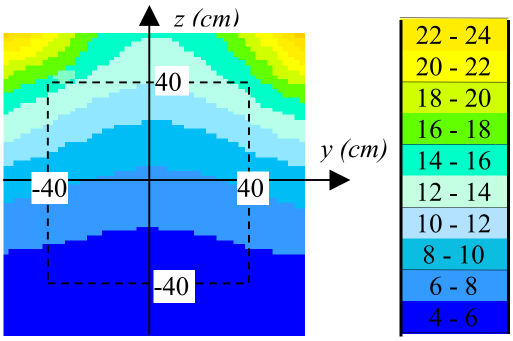

Fig. 10: Total electric field in the yz-plane cell

Effectively, considering the centred 40cm x 40 cm surface, we observe a strong gradient of the z-component of the electric field from approximately 5 V/m to 13 V/m.
However, the use of the opposite plates in balanced mode permits us to improve the field uniformity and the useful test volume. Effectively, by symmetrically feeding the plates X and X' by ½ Watt, the gradient of the z-component of electric field along the z-axis can be significantly reduced as highlighted by the simulated field distribution in figure 11.

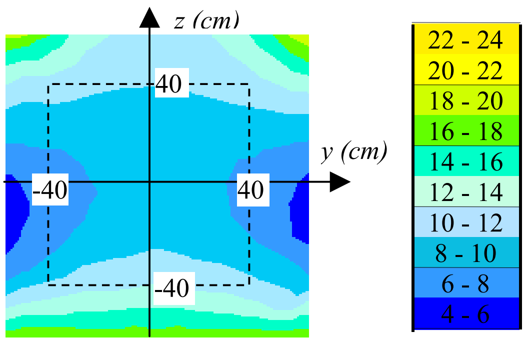

Fig. 11: Total electric field in the yz-plane cell

We can see that in the 40 cm x 40 cm centred surface, we conserve a z-component of electric field which contained between 8 and 12 V/m.

7. CONCLUSION

Concerning the radiation testing, we obtained a satisfying reproductibility compared to the results of radiation testing performed in a conventional TEM cell. We also saw that the repeatability between three series of tests, is as good as that of a conventional TEM cell whereas we placed the EUT in different positions between the three series of tests carried out in the 3-D TEM prototype.
Moreover, simulations results showed that the uniformity of the electric field could be improved in the central volume of the cell by symmetrically feeding the opposite plates. In the final paper, this part will be completed by field measurements.
Through these observations, Three-Dimensional TEM cells could prove an attractive solution for EMC immunity or radiation testing which avoid moving the EUT. Furthermore, knowing that the upper frequency limit is inversely proportional to the dimensions of the structure, small Three-Dimensional TEM cell can be envisaged for small electronic components testing up to relatively high frequencies.

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