Abstract—A reverberation chamber (RC), is an economical facility in EMC, because it allows many directions for illumination an object with a higher field strength compared to conventional techniques, for the same input power. For emission measurements there is no need for moving an antenna. The field uniformity and statistical behavior of the field are important in a RC. This paper presents an evaluation of the performance for three different stirrer designs inside a 1.00 m x 1.30 m x 1.50 m reverberation chamber. The evaluation was done in the frequency range from 300 MHz to 1000 MHz using both simulation and measurement results.

I. INTRODUCTION

Reverberation chamber is rapidly becoming an acknowledged method for the electromagnetic compatibility (EMC) evaluation of electrical and electronic systems. Reverberation chambers are used in the radiated immunity test for components related to automotive, defence and avionic industries. Other typical applications using reverberation chambers are radiated emission test, antenna efficiency and shielding effectiveness of materials and enclosures. The reverberation chamber contains a stirrer that moves and changes the field pattern of the chamber, thus exciting different modes. Other words for stirrer are tuner, or paddle wheel, but we will use the word stirrer throughout this paper. The fields inside a reverberation chamber can be accurately described as isotropic and noncoherent and exhibit a constant, average, uniform field in the large inside volume of the chamber. The reverberation chamber offers some advantages as compared to other facilities for electromagnetic interference (EMI) measurements. A small amount of input power is required to generate a large electric field inside the reverberation chamber. It also provides large working volume and has wide frequency range. The reverberation chamber needs to be evaluated before use, especially by its field uniformity and statistical behavior inside the working volume as described in the standard reverberation chamber test method, IEC 61000-4-21 [1].

Many studies have been conducted using simulation and experiments to show that the uniform field can be generated by rotating a stirrer in a rectangular cavity. Clegg et al. [2] has described an investigation into the optimization of a mode stirrer where the size and the shape of the stirrer have been considered, and genetic algorithm has been used to optimize finer details in the stirrer designs. The model has been carried out using the Transmission Line Matrix (TLM) method for a chamber size of 2.37 m x 3.00 m x 4.70 m. Four different stirrer designs were simulated, namely simple cross shape, V shape, Z shape and random plate. Their work stated that one of the most important considerations in choosing a mode stirrer is its basic shape and the shape that performs best is the complex stirrer. They also found that the stirrer can be improved by increasing its size, although this is limited by the required amount of working volume.

In [3], three kinds of stirrers with different structure and dimension were designed, and the effects of the stirrer on the field uniformity at low frequencies in a reverberation chamber were studied in detail. The results show that field uniformity of the RC could be considerably improved through proper design of the structure and dimension of the stirrer as well as by increasing their number. The Finite Difference Time Domain (FDTD) method has been used in [4] to simulate different forms of the stirrer. The stirrer was formed of eight metallic plates with the dimensions of 0.60 m x 0.40 m oriented in various directions. The result showed the influence of stirrer on the field uniformity and the Lowest Usable Frequency (LUF). Hong et al. [5] described an investigation into the optimization of a stirrer with respect to various parameters including its height and the flap angle. The stirrers with a twin of 5 flaps were analysed inside a 2.40 m x 2.30 m x 3.60 m chamber. They suggested that a reverberation chamber can be successfully operated if careful decisions are made regarding the stirrer design. In [6], the uniformity of the field inside reverberation chamber was investigated using single, two and three stirrers. The synchronized and the interleaved moving modality were analysed for the case of multiple stirrers. The result showed that the interleaved moving modality was better than the synchronized one.

In this paper, three stirrers were modelled and the effect on the field uniformity was simulated. The same stirrers have been built and measurements have been performed. Stirrer 1 is a single flat panel, stirrer 2 is an irregular Z-folded panel and stirrer 3 is an asymmetrical irregular folded one.

II. SIMULATION MODEL

A rectangular chamber of 1.00 m width x 1.30 m height x 1.50 m length is used for the simulation model of a reverberation chamber. The starting frequency, or lowest usable frequency (LUF) depends primarily on the chamber’s dimensions. The dimensions should avoid creating a cubical shape or multiples fractions of each other. The ratios between the width, height and length of a chamber have the effect of producing groups of modes. The chamber’s dimensions
determine the mode density inside it. The simulation model of the RC was developed using CST Microwave Studio. There are three main components in the simulation model; the chamber walls, the transmitting antenna and the stirrer. All the components were modelled using perfect electric conductor (PEC) material. Fig. 1 shows the cross section of simulation model of the RC with a monopole antenna.

![Image](image_url)

Fig. 1 The cross section of the simulation model of the reverberation chamber

A. Chamber Wall

The structure of the chamber was modelled using six sheets of perfect electrical conductor (PEC). One of chamber’s walls was modified to represent the hatch placement.

B. Transmitting Antenna

Because only relative results are compared rather than absolute values, there is no need to model a complex, matched antenna for stirrer simulation purposes, and therefore the RC is excited using a monopole as a transmitting antenna. The monopole is mounted on a chamber’s wall, using it as a ground plane. The monopole antenna was designed to operate for the centre frequency of 600 MHz. It is located 0.65 metres from the chamber’s floor.

C. Stirrer

The statistical behaviour of the reverberation chamber has been analysed using three different stirrer designs. The vertical orientations of the stirrer are selected to be in the same position for consistent comparison. Stirrer 1 has one flat plate with 1.20 m high and 0.40 m wide. Stirrer 2 has six 0.40 m wide plates with irregular Z folded configuration. The plates were arranged in different folding angles. Stirrer 3 is formed of seven continuously connected plates oriented in various folding and slanting angle. All the designed stirrers are shown in Fig. 2.

Electric field probe data were collected from the eight locations that form the corners of the working volume as in Fig. 1. Probe 1, 2, 3 and 4 were located 0.46 m above the chamber’s floor, while probe 5, 6, 7, and 8 were located 0.90 m from the chamber’s floor. The distances of the probes from the nearest chamber’s wall were 0.25 metres. Electric field data were analysed to determine the field uniformity within the working volume. Stirrers are rotated anticlockwise about the z axis at 72 different rotation angles.

![Image](image_url)

Fig. 2 Stirrer 1 (flat panel), stirrer 2 (irregular Z-folded) and stirrer 3 (asymmetrical irregular folded)

![Image](image_url)

Fig. 3 From left: Stirrer 1 (flat panel), stirrer 2 (irregular Z-folded) and stirrer 3 (asymmetrical irregular folded)

![Image](image_url)

Fig. 4 The layout of equipment in the reverberation chamber
III. MEASUREMENT SETUP

The measurements have been conducted in a reverberation chamber of the same dimensions as the simulated one, i.e. 1.00 m x 1.30 m x 1.50 m. The three analysed stirrers, shown in Fig. 3, have been built and closely correspond to their simulation models. For instance, the asymmetrical irregular folded stirrer has been folded on the places where a laser removed some aluminium. The initial tests with an omnidirectional transmitting antenna placed close to the working space and isotropic field probes indicated that a significant amount of unstirred components were present. Therefore, it was decided to use a directional log-periodic antenna as a transmitter, which was aimed at the stirrer. Because the frequencies around the lowest usable frequency [1] of the chamber are the main point of interest, and because directional antennas are usually larger than omnidirectional ones, the transmitter occupied a part of the working volume, not allowing for measurements in the same 8 positions as suggested in the standard [1]. Therefore, only a single monopole antenna was used as a receiver. The monopole antenna was placed perpendicularly to the polarization of the transmitter, minimizing the direct coupling between them, as shown in Fig. 4. The setup was automated using LabVIEW software and utilizing a spectrum analyser with a tracking generator, giving 551 measurement points in the frequency range between 300 MHz and 1 GHz. Such a measurement has been performed every 1 degree rotation for each stirrer configuration.

IV. RESULTS

The results obtained by the means of both simulation and measurement are presented in this chapter. The stirrers have been evaluated according to 2 categories described in IEC 61000-4-21: the field uniformity test and the calculation of the number of independent samples. In addition the autocorrelation of the stirrer has been evaluated.

A. IEC 61000-4-21 Field Uniformity Test

The field has been calculated in 8 spatial positions only in the simulations, therefore no measurement data is analysed in this part. Figures 5-7 show the standard deviation as defined in the IEC 61000-4-21 standard for simulated electric field data for three different stirrer designs. The chamber is considered to pass the field uniformity requirements provided that the standard deviation for both the three individual field components, $E_x$, $E_y$, and $E_z$, and the total data set, $E_{total}$, are within the IEC 61000-4-21 limit. The field within the chamber is considered uniform if the standard deviation is within 3dB above 400 MHz, 4dB at 100 MHz decreasing linearly to 3 dB at 400 MHz. In the simulation, many more frequency points were calculated than the IEC standard suggests, therefore it is more likely to obtain a point where the limit is crossed. However, such a large amount of data allows to compare the three stirrers in a more accurate way. The comparison highlights that stirrer 2 has the best performance in terms of field uniformity. However, it is very important to mention that the rotation volume of stirrer 2 is significantly greater than the volume of the other two stirrers. The comparison of stirrer 1 and stirrer 3, which have similar volumes, indicates better performance of the latter.

B. IEC 61000-4-21 Number of Independent Samples

The second parameter influenced by the stirrer performance is the number of independent samples. This calculation has been conducted according to the IEC 61000-4-21 standard. The number of independent samples is proportional to the rate of change of the autocorrelation coefficient, i.e. the angle after the coefficient drops below 1/e threshold defines the average angle difference between independent samples.

The results obtained by simulations and measurements are presented in Fig. 8 and 9 respectively. In the graphs with so many frequency points present, a moving average filter has been applied to make them more readable and easier for
comparison. The absolute measured number of independent samples for all stirrers is greater than the simulated number most likely due higher angle change resolution. However, the relative comparison of the obtained results, i.e. the differences between the stirrers, delivers the same conclusions for both simulations and results. It can be observed that in both cases, stirrer 1 and stirrer 2 behave similarly and better than stirrer 3. Again, it has to be mentioned that a greater volume of stirrer 2, mentioned in the previous paragraph, has a significant impact on this result.

C. Autocorrelation

Stirrer 1 is a flat panel so it has a periodicity of 180 degrees, i.e. has a similar shape at 0 and at 180 degrees. The autocorrelation coefficient using stirrer 1 is presented in Fig. 10. The initial rate of change, i.e. slope, is rather high and thus the first crossing of the $1/e$ threshold is already present at low angle change. But the flat structure of stirrer 1 creates a periodicity of the boundary conditions after 180 degrees, which is indicated by a high peak in the discussed graph. Stirrer 3 has much less periodicity and is much less prone to create a repeated field structure, as can be concluded from the autocorrelation coefficient, also shown in Figure 10.

This phenomenon, which can significantly overestimate the stirrer evaluation, is not taken into account in IEC 61000-4-21 method.

V. CONCLUSIONS

The statistical behaviour has been evaluated for three different stirrer designs in a reverberation chamber. Simulations and measurements have been performed to compare the performance of stirrers in the chamber. The IEC 61000-4-21 field uniformity test, run on the simulated data, has shown that the irregular Z-folded stirrer 2 has the best performance. It is, however, a result of its much greater rotation volume when compared to stirrer 1 and stirrer 3. From the latter two, which have the same rotation volume, the highly geometrically complex stirrer 3 performs better than the flat stirrer 1.

Although there are certain differences between the absolute results of the number of independent samples calculation, the relative comparison of both measurements and simulations deliver the same conclusions. Again, the superior volume of stirrer 2 has a larger impact on the performance than the high geometrical complexity of stirrer 3. According to the IEC independent sample calculation, stirrer 1 behaves similarly to stirrer 3. However, after taking a closer look at the autocorrelation coefficient, it can be concluded that this is not a suitable evaluation method for stirrer 1 due to its periodic behavior, which can greatly overestimate the test outcome.

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