CST Simulation of Reverberation Chamber for Improved Field Uniformity

Bulent URUL[1], I. Bahadir BASYIGIT[2], Tuna GOKSU[3], Selcuk HELHEL[4]

[1,2]Department of Electronics and Communication Engineering, Süleyman Demirel University, Isparta, Turkey
bulenturul@sdu.edu.tr, bahadirbasyigit@sdu.edu.tr,
[3]Department of Electrical and Electronics Engineering, Süleyman Demirel University, Isparta, Turkey
tunagoksu@sdu.edu.tr
[4]Department of Electrical and Electronics Engineering, Akdeniz University, Antalya, Turkey
selcukhelhel@akdeniz.edu.tr

Abstract

Reverberation Chamber is a recent and influential testing cite for the electromagnetic compatibility tests. This chamber is extensively used in these tests due to the several reasons: They ensure a large working volume and also cheaper than other test chambers. In addition, they provide statistically field uniformity that is a key indicator when undertaking a study on a reverberation chamber. In this paper, a RC with the actual dimensions has been built by the CST model and electric field strength has been calculated according to three locations of stirrer. All results in 3-dimensions are about 1dB below the proposed limit of International Electrotechnical Commission standard IEC 61000-4-21 suggestion. Observed results show that stirrer position is a predominant effect on field uniformity, and for obtaining more precise uniform electric field volume with very low standard deviations at a certain frequency or a narrow bandwidth, one needs to focus on stirrer position as well as frequency.

1. Introduction

In recent years, execution of a Reverberation Chamber (RC) in electromagnetic compatibility measurement have savored sudden development and more and more attention. RCs have several advantages that provide larger working volume, better field uniformity, lower costs etc. RC has been accepted by many international standards, including the 1999 publication of the United States military standard ML-STD-246E and 2003, published by the International Electrotechnical Commission standard IEC 61000-4-21[1].

Generally the RCs are used in very high quality factor (Q) shielding shell equipped with mechanical stirrer, to continuously change the electromagnetic field distribution within the model. Electromagnetic environment of the reverberation chamber has the following characteristics: a) space evenly: Interior energy density; b) isotropy: the flow of energy is the same in all directions; c) random polarization: the phase angle between waves and all wave polarization is random.

The field uniformity of study area and operating frequencies is 2 key performance indicators of the RC. Field uniformity of the study area is as well as possible in RC.

There are also several methods and ways to analyze RC parameters in literature. Diffusion equation-based modeling of the diffuse EM field in enclosed spaces is a natural generalization of the PWB (power balance) method can predict field non-uniformity in loaded RCs, informing the optimal positioning of antennas to minimize the systematic error due to the loading [2]. A general method for determining the number of independent stirrer positions in reverberation chambers is presented [3]. The total scattering cross section (TSCS) has been proven to be an effective quantity to characterize the performance of stirrers in a RC [4]. A full-wave finite-difference time-domain (FDTD) code is adopted to simulate a large RC including stirrers, actual antennas, and losses [5]. The behavior of a mode-stirred RC has been analyzed at millimeter waves around 60GHz taking into account mechanical, electromagnetic, and measurement constraints for operation in Ka, U, and V bands [6]. The performance of a mechanical stirrer is numerically investigated, when its rotation axis is moved parallel to the three Cartesian axes in the reverberation chamber [7].

In this study, computer simulating technology on microwave (CST™-MW) based on finite integration technique (FIT) in time-domain [8] is used to acquire accurate modeling results for comprehensive analysis of field uniformity of RC in 100-600MHz in many different viewpoints. In this paper, three different parameters have been investigated: The effect of field uniformity, electric field and stirrer orientation have been analyzed and investigated to get more useful suggestions to designers in conclusion.

Aim of this paper is, by using this simulation model to analyze parameters that effect RC in detail and to give suggest device producers to get better performance against to EMI.

Paper is organized as follows: Section 2 notice the structure of RC that helps to understand RC and RC parameters. Section 3 gives simulation and test set up and it includes the analysis of simulation results of RC versus frequency and section 5 contains conclusion of results which have been investigated in Section 4 and future work.

2. Structure of Reverberation Chamber

RC mainly consists of the following three parts: Shielding cavity, stirrer, receiving and transmitting antennas.

Shielding cavity: wall materials of shielding cavity must have relatively good reflection properties like galvanized steel sheet to meet the requirements of high Q value of the reverberation chamber [9]. RC is widely in rectangular shape, and chamber size is usually required at the lowest usable frequency (LUF). The size of the equipment under test (EUT) and the desired minimum operating frequency are two factors to determine dimensions of a RC.

Stirrer: Stirrer is one of the most important parts of the RC. Waves of reflections and scatterings create repeatedly by the stirrer and indoor wall surfaces. As the stirrer and all wall surfaces are good conductor, the loss are quite low, after repeatedly reflection and scattering signal mutual overlay, which makes the power density in partial space increase, forming strong space field strength, while some location may get low field strength due to anti-phase overlay. Through the movement of the stirrer, reflection and scattering characteristics of stirrer field strength values randomly changes, so that every point in the work area have been able to meet the expectations of high field strength [10]. According to IEC standards stirrer radius shouldn't be less than λ/4 (λ for reverberation chamber's lowest usable frequency corresponds to the wavelength), generally choose λ/3~λ/2, its greatest dimension shall be not less than three-fourths of reverberation chamber minimum size.

Receiving and transmitting antenna: Antennas can be selected according to the frequency range.

3. Simulation and Test Set Up

The diagram of simulated reverberation chamber can be seen in Fig. 1, and it is 8.8 x 6.9 x 4.8m (length x width x height) size. Instead lowest useful frequency (LUF) is calculated as 90MHz, 100MHz was chosen as LUF in order to provide the stabilization of data. LUF is expressed as f_s in related equations. Three pieces of metal blade have taken into account during simulation that they are a metal rotation axis sustaining the metal blade and two brackets buildup the mechanical stirrers together. The length, the width and the thickness of each piece of metal blade are 180cm, 180cm and 1cm. The angle of any blades is set to 90° (the angle can be changed according to practical situation).

A transmitting antenna which is waveguide port and 12 receiving probes have been located as seen in Fig. 2 and Fig 3. Simulation is run in the frequency range of 100-600MHz. Reference antenna location is randomly selected. E-field probe can be placed at any location in the chamber working volume. There are 12 probe locations within the volume in this study. E-field probe is used to obtain the amplitude of the electromagnetic field in three orthogonal directions in the reverberation chamber. Instead IEC 61000-4-21 standard recommends getting the electric field at least 8 positions around the working volume, electric field at 12 positions are selected, simulated and calculated in order to improve accuracy (Fig.3). The working volume is defined as being a distance of at least λ/4 from the walls of the chamber and from any antenna, stirrer, or other object at the lowest frequency of operation. For this chamber operating above 100MHz, this is 0.75m.

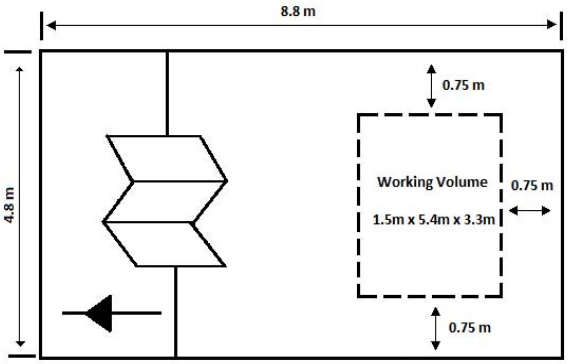


Fig.1. Schematic diagram of the RC

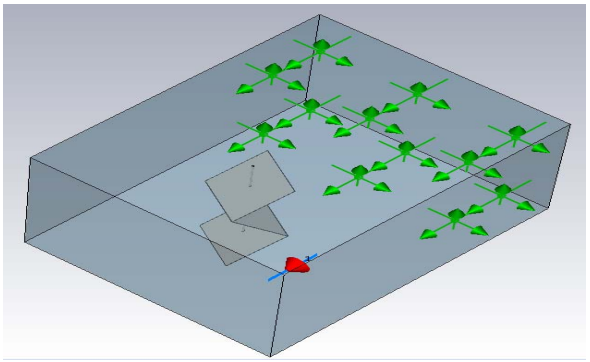


Fig.2. Simulation and test set up of reverberation chamber

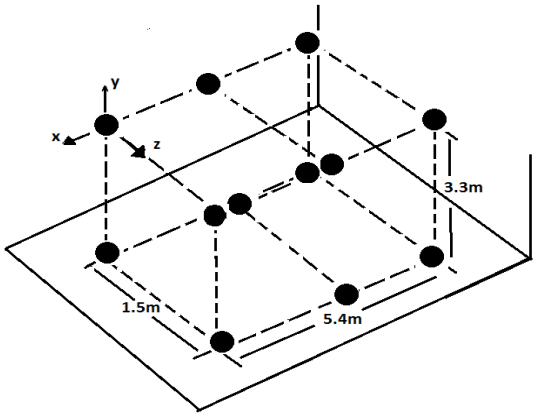


Fig.3. E-field probe positions for measuring the electric field.

The standard recommends the usage of 20 different frequencies between f_s - $3f_s$ interval and 15 frequencies between $3f_s$ - $6f_s$ intervals as tabulated in Table 2. According to standard recommendation, 20 different logarithmically spaced frequencies in the range of 100MHz-300MHz and 15 different logarithmically spaced frequencies in the range of 300MHz-600MHz are used. But these frequencies should be logarithmically spaced (Table 3). The stirrer 0.5m apart from each other is placed at three different locations in order to compare the effect of stirrer positions over the field uniformity of reverberation chamber. The simulation is carried out for the each stirrer location.

Table 1. The Stirrer Locations

Stirrer	X	Y	Z
1	0	0	1.5
2	-0.5	0	1.5
3	-1	0	1.5

Table 2. Sampling Requirements

Frequency Range	Number of samples recommended for calibration and test	Number of frequencies required for calibration
fs to3 fs	50	20
3fs to 6 fs	18	15
6fs to10 fs	12	10
Above 10 fs	12	20/decade

Table 3. Logarithmically Spaced Frequency List

fs=100MHz	fs to 3fs	3fs to 6fs
1	100	300
2	105.95261	315.22698
3	112.25955	331.22685
4	118.94192	348.03882
5	126.02206	365.7041
6	133.52366	384.26602
7	141.47179	403.77005
8	149.89306	424.26406
9	158.8156	445.79827
10	168.26926	468.4255
11	178.28568	492.20122
12	188.89832	517.18368
13	200.14269	543.43418
14	212.0564	571.01709
15	224.67928	600
16	238.05355	
17	252.22395	
18	267.23784	
19	283.14547	
20	300	

4. Effect of Field Uniformity

The empty chamber field uniformity calibration should be carried out after RC has been built in CST model. This process should be implemented without the test bench and EUT in the working volume. The capability of RC is better when the field uniformity testing volume is better. The reference of field uniformity of reverberation chamber in the IEC 61000-4-21 standard is shown in Table 4.

Table 4. Field uniformity tolerance requirements

Frequency Range	Tolerance requirements for standard deviation
80 MHz to 100 MHz	4dB
100 MHz t0 400 MHz	4dB at 100 MHz decreasing linearly to 3 dB at 400 MHz
Above 400 MHz	3 dB

The field within the chamber is considered uniform if the standard deviation is within 3dB above 400MHz, 4dB at 100MHz decreasing linearly to 3dB at 400MHz, and within 4dB below 100MHz.

The field uniformity is specified as a standard deviation σ from the normalized mean value of the normalized maximum values obtained at each of the eight locations during one rotation of the stirrer. σ is calculated using data from each probe axis independently and the total data set. σ of the RC is calculated at the standard deviation of the total maximum electric field data as follows:

$$\sigma = \sqrt{\frac{\sum_{m=1}^{m}\sum_{n=1}^{n}(E_{m,n} - E_{m\times n})^2}{(m\times n)-1}} \quad (1)$$

where m is the total position number of the maximum electric field measurement antenna, n is the total coordinate axis number at any position (if components of the maximum electric field strength measured x, y, and z axis), and $E_{m\times n}$ is the average maximum electric field. For this work, m is 6 and n is 2, at total 12 probes have been used. The standard deviation is expressed in *dB* relative to the mean using the following equation [11, 12]:

$$\sigma = 20\log\left(\frac{\sigma + E_{m\times n}}{E_{m\times n}}\right) \quad \text{[dB]} \quad (2)$$

5. Results and Conclusions

Three stirrer locations which are shown in Table-1 and 12 probes which are placed at 12 different locations as shown in Table-5 is used to observe electric field uniformity in the reverberation chamber. The electric field strength has been measured for 20 different angles of the stirrer rotation and 3 stirrer locations by each of 12 probes in the range of 100-600MHz. So 20x3x12=720 values for electric field are obtained and 12 of them are chosen from them as maximum.

Fig.4 demonstrates the results for the first location of stirrer. The highest maximum electric field strength (50.274 V/m) is obtained at 105.95 MHz by means of seventh probe (-2.7, 1.65, -2.15) and the lowest maximum electric field is measured as 11.02 V/m by means of fifth probe (2.7, 1.65, -2.15) at 133.52 MHz. Frequency band of 150-250MHz and 400-500MHz are relatively more uniform in three dimension than the rest whole band.

Table 5. Probes Locations

Probes	X	Y	Z
1	0	1.65	-2.15
2	0	-1.65	-2.15
3	0	1.65	-3.65
4	0	-1.65	-3.65
5	2.7	1.65	-2.15
6	2.7	-1.65	-2.15
7	-2.7	1.65	-2.15
8	-2.7	-1.65	-2.15
9	2.7	1.65	-3.65
10	2.7	-1.65	-3.65
11	-2.7	1.65	-3.65
12	-2.7	-1.65	-3.65

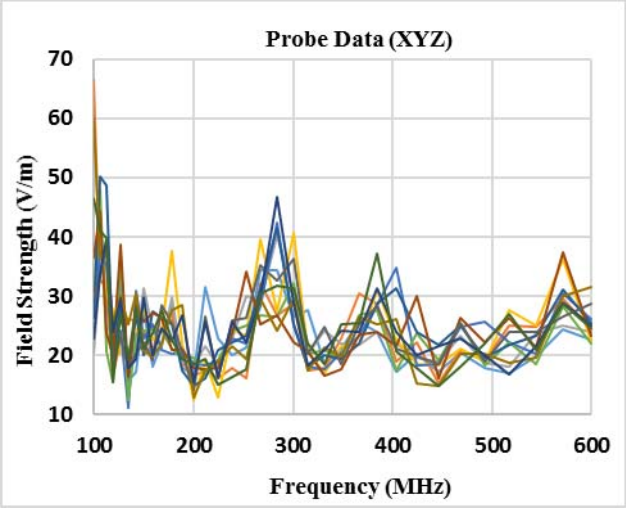


Fig.4. Maximum Electric Field Strength (V/m)

In Fig.5, standard deviation of maximum electric field due to first stirrer is shown. All results in 3-dimensions are about 1dB below the proposed limit of International Electrotechnical Commission standard IEC 61000-4-21 suggestion. These results indicate that the reverberation chamber having a size of 8.8 x 6.9 x 4.8m (length x width x height) has sufficiently uniform electric field working volume.

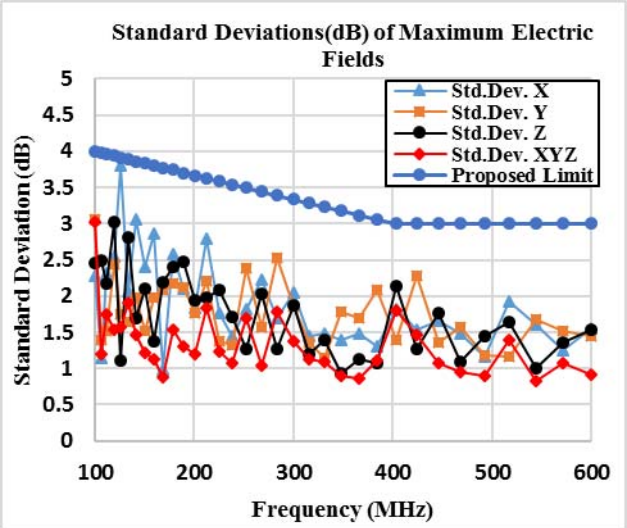


Fig.5. Standard Deviation of Max. Electric Fields

In Fig.6 total standard deviation of maximum electric field variation due to three different stirrer locations is shown. In this case, field uniformity is about 2dB and more below the proposed limit except one location at 100MHz exact frequency. Electric field uniformity can be better or worse by changing the location of stirrer for a specific frequency or a narrow bandwidth. For example, a standard deviation closer to zero is obtained at the 403.77 MHz by changing the position of stirrer. Similarly, changing the location of stirrer provides better electric field uniformity at the range of 252-300 MHz. Even the best result is achieved as 0.499dB at 331.23 MHz by bringing the stirrer position to the 3rd location (-1, 0,1.5).

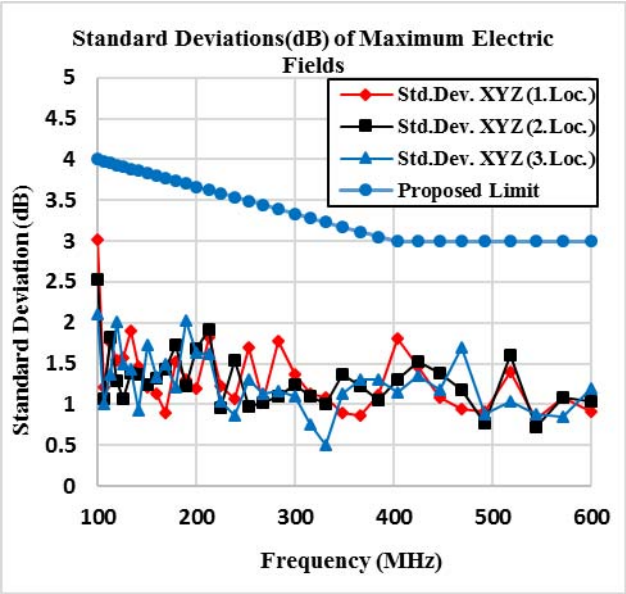


Fig.6. Standard Deviation of Max. Electric Fields (For Locations of Stirrer)

This work aimed to model electric field level in the reverberation chamber depending on positions of stirrer and frequency. For this aim, the electric field strength is measured at a certain number of measurement points within a defined test volume using an isotropic field probe in the simulation. Observed results show that stirrer position is a predominant effect on field uniformity, and for obtaining more precise uniform electric field volume with very low standard deviations at a certain frequency or a narrow bandwidth, one needs to focus on stirrer position as well as frequency.

The proposed study provides higher prediction capability for each one stirrer position and the studied frequency band. Simulation results show that proposed model is quite matched with the actual electric field levels.

Funding

This work was supported by The Department of Scientific Research Projects in Süleyman Demirel University named as "*An Investigation of Effect of the Stirrer Position in Electric Field Uniformity in EMC, Reverberation Chambers and its Modeling"* and in Turkish "*EMC Yankı Odalarında Karıştırıcı Konumunun Elektrik Alan Düzgünlüğüne Etkisinin İncelenmesi ve Modellenmesi* " [Project Number: 3974-D2-14]. We also would like to Akdeniz University Scientific Research Projects Support Unit (BAP) and Akdeniz University BAP and EMUMAM directorate (Grant Number:2007K120530-DPT).

1. References

[1] IEC 61000-4-21:2003, *Electromagnetic compatibility (EMC) - Part 4-21: Testing and measurement techniques - Reverberation Chamber Test Methods*[S].J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[2] I. D. Flintoft et al., "Evaluation of the Diffusion Equation for Modeling Reverberant Electromagnetic Fields", *IEEE Transactions on Electromagnetic Compatibility*, vol. 59, no. 3, pp. 760-769, June, 2017.

[3] S. Pfennig, "A General Method for Determining the Independent Stirrer Positions in Reverberation Chambers: Adjusting the Correlation Threshold", *IEEE Transcation on Electromagnetic. Compatibility*, vol. *58,* no. *4,* pp. *1252-1258,* Aug., 2016.

[4] Q. Xu et al., "The Limit of the Total Scattering Cross Section of Electrically Large Stirrers in a Reverberation Chamber", *IEEE Transactions on Electromagnetic Compatibility Letters*, vol. 58, no. 2, pp. 623-626, April, 2016.

[5] L. Bastianelli et al., "Evaluation of stirrer efficiency varying the volume of the reverberation chamber", *in Proceedings of IEEE International Symposium on Electromagnetic Compatibility (EMC)*, Ottawa, ON, Canada, 2016, pp. 19-24.

[6] A. K. Fall et al., "Design and Experimental Validation of a Mode-Stirred Reverberation Chamber at Millimeter Waves", *IEEE Transactions on Electromagnetic Compatibility*, vol. 57, no. 1, pp. 12-21, Feb., 2015.

[7] L. Bastianelli et al., "Stirrer Efficiency as a Function of its Axis Orientation", *IEEE Transactions on Electromagnetic Compatibility Letters*, vol. 57, no. 6, pp. 1732-1735, Dec., 2015.

[8] Computer Simulation Technology, CST-MW Studio, 2015,

[9] C. Bruns and R. Vahldieck, "A Closer Look at Reverberation Chambers - 3-D Simulation and Experimental Verification". *IEEE Transactions on Electromagnetic Compatibility*., vol.47, no.3, pp.612-616, Oct. 2005.

[10] Y. Huang et al., "A novel method to examine the effectiveness of a stirrer", *in Proceedings of IEEE International Symposium on Electromagnetic Compatibility (EMC)*, Chicago, IL, USA, 2005, pp. 556-561.

[11] Y. J. Wang and et al., "Coupling Cross Section and Shielding Effectiveness Measurements on a Coaxial Cable by both Mode-Tuned Reverberation Chamber and GTEM Cell Methodologies", *Progress In Electromagnetics Research, PIER*, vol. 47, pp. 61-73, 2004.

[12] N. K. Kouveliotis and et al., "FDTD Modeling of a Vibrating Intrinsic Reverberation Chamber", *Progress In Electromagnetics Research, PIER*, vol. 39, pp. 47-59, 2003.