Standard Deviation Characterization of a Small Size Reverberation Chamber by Using Full-wave Simulation and E-Field Probe

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Abstract

Reverberation Chamber (RC) is a new type of measurement equipment used in electromagnetic compatibility and antenna tests and capable to produce an almost uniform electric filed inside a Working Volume (WV). In this paper, the field uniformity of an actual small size RC is studied. At first, the mode density of the chamber which should be larger than unity is investigated. In the next step, the Standard Deviation (SD) of a small size RC, as a field uniformity criterion is investigated in an existing RC. A highly detailed three-dimensional model of chamber including its stirrers, antenna, WV, and its door create to verify the field uniformity of a RTS60 reverberation chamber. The removal of reverberation chamber's stirrers shows that they have a direct effect on the uniformity of field. As the stirrer moves during the test, the effect of three different position of stirrer on the field uniformity is investigated. The transmission antenna, as an important component of these rooms, is simulated and investigated separately. The reflection coefficient of that antenna fit the working frequency band of the chamber. In a real scenario, the SD of the chamber is measured by using an electric field probe. A comparison between the simulation and measurement also is done in order to confirm the uniformity of the electric fields.

Keywords: Reverberation chamber; stirrer; Electromagnetic Compatibility tests; Antenna gain and efficiency; standard Deviation.

1- Introduction

As technology spreads in every aspect of human life, we need electrical devices to work side-by-side without interfering with each other operation. Electromagnetic Compatibility (EMC) standards and consequently tests have been defined to ensure the proper performance of electronic equipments in the vicinity of each other and in different electromagnetic conditions [1]. To test and study the effects of electromagnetic wave's interference on electrical device, some standard tools, which provide uniform field distribution within specific environments, has been designed and implemented. The importance of field uniformity is to simulate the actual interference condition.

Today, various test rooms, including acoustic anechoic chambers [2] , RF shielded Room [3] , radio-frequency anechoic chambers [4] , semi-anechoic chambers [5] and GTEM CELL [6, 7] , are designed and manufactured to perform various tests, including antenna testing, radar cross-section testing, and EMC testing. Reverberation chambers, which is the most recent invention in this regard has been more successful in implementing the real situation compared to other rooms [8] . In recent years, the use of RC in the measurement of electromagnetic compatibility has become more prominent. Measurement of radiated power and antenna efficiency are two commonly capability of this type of rooms. Furthermore, enclosure shielding enables multipath environments simulation, and biological effects studies [2].

These rooms have a relatively large WV that capable measuring the characteristic of large device. Beside of that

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the RC is economically more cost effective than other test rooms. The field uniformity in the WV is the main feature of this chamber. Furthermore this room have been accepted by many international standards, including the US military industry standard ML-STD-246E, which was issued in 1999 [9] , and the international standard IEC61000-4-21, which was issued in 2003 [10].

Many studies have done to investigate the characteristics of RCs. Reference [11] provides a general method for determination of the number of independent stirrer positions. The Total Scattering Cross Section (TSCS), which is a proper parameter to describe the performance of the stirrer in the reflection chamber, is presented in Reference [12]. In terms of RC simulation, the structures of RC are electrically very large (in the order of *100×100* wavelengths). So the simulation is made very time consuming and difficult specially because mode-stirrer are moving during the operation of RCs. Reference [8] explores the full-wave Finite-Difference Time-Domain (FDTD) method for simulating large Reverberation chambers with realistic stirrers and antennas. In Reference [13] the performance of the mechanical stirrer in the reflection chamber is numerically investigated.

As we were to use our RC, it was also important to us to investigate the important characteristics of the room. Moreover, this help us to repeat it when designing a new RC or making any change in the current one. In our paper for the first time, the SD characteristics of an RC has been compared and studied practically in measurements and in full wave simulation. The first important parameter of a RC is its field uniformity and SD over the working frequency band. Having the fact that no full wave characterization of SD has been reported before. For this purpose, our RTS60 Bluetest reverberation chamber in Wireless Terminal Measurement laboratory (WiTeM) of K.N.Toosi University of Technology, which is to the authors' knowledge the only small size RC in Iran, has been selected. The RC is modeled and simulated in CST Microwave Studio with maximum details. To validate the simulation results the practical measurement performed based on requirement of standards. The field obtained by both methods, is used to analyze the field uniformity in term of SD parameter. In addition, the effect of stirrer motions and WV rotation on field uniformity are investigated. The measured and simulated results show that the field all over the Working Volume (WV) is distributed uniformly for different position of stirrers.

This paper is organized as follows. In section II, different parts of a RC is briefly introduced. Section III introduces the SD criterion and its requirement. The RTS60 dimensions and components are shown in section IV. The CST modeling is described in section V. The practical test procedure and the results discussed in section IV.

2- Reverberation Chamber Structure

Reverberation chambers have many advantages including a large working volume, better field uniformity, lower construction costs, etc. The structure of RC generally made of high quality factor shielded rooms with one or more stirrers to change the distribution of the electromagnetic field. Two important features that distinguish the RC from the other rooms are isotropic field and random polarization. The isotropic field causes the energy is distributed uniformly in all direction and the random polarization provides the randomly polarization of the radiated waves. These features make the RC test environment more similar to realistic environment. The statistical field uniformity criteria and operating frequency are two key specifications for the performance of the reverberation chambers.

The RC generally consists of the following sections: shielding cavity, stirrers, antennas and working volume. All the component of the RC must be isolated from the unwanted external field, Thus they are put inside a shielded cavity. The material of shielding cavity walls should be from a very good conductive material such as galvanized steel sheets. This feature provides a high quality factor (Q). The shape of reverberation chambers is generally rectangular, and the size of the chambers depends on the lowest frequency. As the chamber size became larger the operation frequencies, became smaller [14]. . The positions of different components inside the shielding cavity of RTS60 RC are shown in Fig.1.

Stirrers are one of the key components in a reverberation chamber which enable use creating a uniform field distribution by manipulating electromagnetic fields. The inner walls and the stirrers often reflect the electromagnetic waves transmitted by the antenna. The movement of the stirrer inside the room maximizes the field strength in the WV. The main purpose of these stirrers is to create a variable electromagnetic field with amplitude that is statistically uniform. According to the IEC standard, the stirrer radius should not be less than $\lambda/4$ (λ wavelength minimum operating frequency). Generally the stirrer radius is chosen between $\lambda/2-\lambda/3$ and also the largest stirrer dimension should not be less than 3/4 smallest dimension of the chamber [10]. One, two, or three Stirrer blades are usually used in RCs.

In a rectangular cavity, the number of resonance modes is calculated by equation (1)[15]

$$N=\frac{8\pi}{3}(a\times b\times d)\frac{f^3}{c^3}-(a+b+d)\frac{f}{c}+0.5 \quad (1)$$

where N is the number of modes, a,b,d are the dimension of cavity, f is the frequency and c is the speed of light. The mode density is defined as $D_{S(f)}=dN/df$ for each cavity resonator. For rectangular cavity, this parameter can be calculated from equation (2) based on equation (1)[15].

$$D_{S(f)} = 8 \times \pi(a \times b \times d)\frac{f^2}{c^3} - \frac{a+b+d}{c} \qquad (2)$$

In order to have field uniformity in a RC this parameter must be higher than unity. The modes stimulated inside this chamber could be estimated by the first-order modes stimulated in an ideal rectangular cavity. These modes are combined by the mechanical stirrers inside the chamber to change the boundary conditions. Each mode has a different resonant frequency compared with the ideal initial chamber modes. When the mechanical stirrers start moving, the resonant frequencies of these modes varied. Combination of these modes results in a complex Gaussian field distribution throughout the chamber[15].

Regarding the working frequency, any type of antenna which works in this band can be selected as transmitter antenna. The number and the locations of the antennas inside the RC are determined by the type and the pattern of antenna.

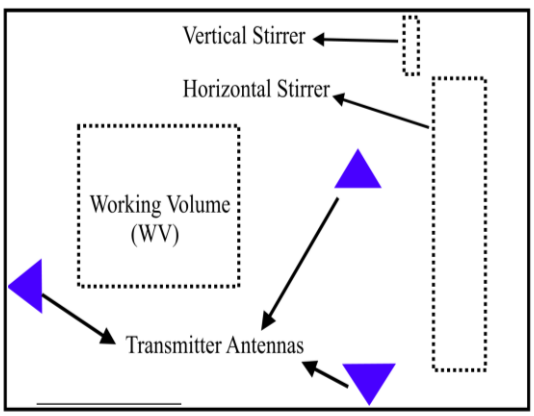


Fig 1 Main components of a RC

The field inside the reverberation chamber is statistically uniform only in the working volume of the chamber (WV). According to the IEC 61000-4-21standard, the working volume is a rectangular area that should be positioned at the opposite side of the room where stirrers are. Also the minimum distance of the WV from the walls, stirrers, antennas or anything else should be $\lambda/4$ [10].

In this work, a RTS60 RC, made by Bluetest AB is used as the test platform. The structure of the RTS60 is shown in Fig. 2. This chamber has dimensions of 1.75m×1.88m ×1.75m. This chamber has 100 dB shielding that is capable for measuring receiver sensitivity without disturbing external wireless devices such as cell phones. By using these dimensions, the mode density of RTS60 can be calculated by equation (2) .In Fig. 3, the mode density of RTS60 in frequency band of 600-6000 MHz is shown. As illustrated in this figure, the mode density is higher than 1 within the working frequency of the chamber.

According to the IEC standard, the lowest operating frequency of a room can be obtained by multiplying the lowest resonant frequency by a factor of 5 or 6 [16]. For our reverberation chamber with the mentioned dimensions, the lowest resonant frequency is approximated to be 100 MHz. Therefore, the lowest operating frequency of RTS60 is approximately 600 MHz. The upper working frequency of this structure is determined 6 GHz by company.

Fig. 2 RTS60 chamber in WiTeM lab, KN Toosi University of Technology

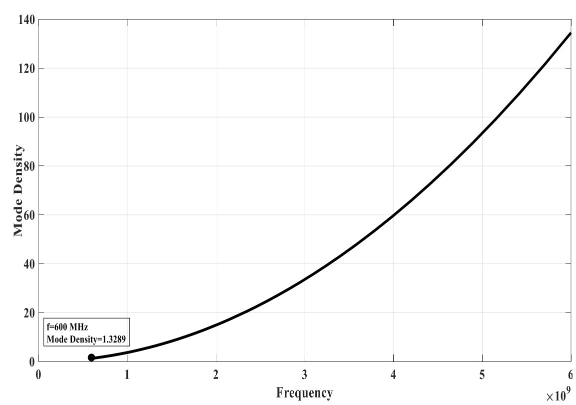


Fig. 3 Mode density of RTS60 for different frequency

3- Field Uniformity Parameter

The field uniformity parameter or Standard Deviation (SD) is one of the most important parameters that must be determined in order to show that statistically the electric field is uniform in the reverberation chambers. According to IEC61000-4-21, the field inside the reverberation chamber is considered uniform if its SD is lower than the threshold that is determined for each frequency. The standard explains that the acceptable SD is below 4 dB from 80 MHz to 100 MHz frequency range. The standard value decrease linearly to 3 dB from 100 MHz to 400MHz, and in frequency higher than 400 MHz is below 3 dB [10]. For a give chamber, SD or σ can be obtained by equation (3)[16] :

$$\sigma = \sqrt{\frac{\sum_{m=1}^{M}\sum_{n=1}^{N}(|E_{m.n}| - |E_{m\times n}|)^2}{(M \times N) - 1}} \tag{3}$$

where *n* varies among three *(N=3)* coordinate axes, usually three *x,y,z* axes, and *m* denotes the number of electric field probes selected in the WV that in our case *M=8*. The IEC recommends to place at least eight probes in the WV. By using the data obtained from probes, the maximum electric field *($E_{m.n}$)* and, the average of the maximum electric field *($E_{m\times n}$)* calculated. The value of *σ* in dB can be obtained as follows [16]:

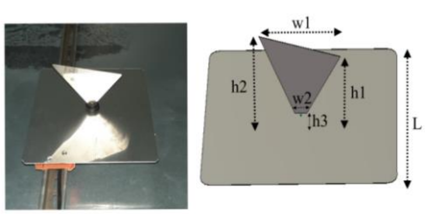
$$\sigma = 20\,log\left(\frac{\sigma + |E_{m\times n}|}{|E_{m\times n}|}\right) \qquad (dB) \tag{4}$$

In a reverberation chamber, it is not necessary to obtain measurement parameters in all frequencies. According to the IEC 61000-4-21standard, it is enough to set twenty frequency points logarithmically within the frequency range *fs* to *3fs*, fifteen frequency points within the frequency range *3fs* to *6fs*, and finally ten frequencies points within the frequency band *6fs* to *10fs*.

4- Full Wave Simulation of RC

The excitation antennas are Bow-Tie Blade Monopole antenna that fixed at the three chamber walls. The antennas are installed perpendicularly in order to produce wave in all directions uniformly. As shown in Fig.4, the Bow-Tie Blade Monopole is simulated in CST Microwave Studio using its real dimension. The main parameters of the antenna are summarized in Table 1.

The reflection coefficient of the antenna is presented in Fig. 5 showing that it works within the chambers frequency band. The antenna's S_{11} is below -10 dB from 600 MHz up to 6 GHz. The monopole like radiation pattern of the antenna in 3 GHz is also presented in Fig. 6



a) b)

Fig. 4 Bow-Tie Blade Monopole Antenna used in the RTS60
a) fabricated model b) simulated model in CST Microwave Studio

Table 1 Main parameter of the antenna

Parameter	Value
L	*20 cm*
h1	*4.9 cm*
h2	*6.4 cm*
h3	*0.4 cm*
w1	*11 cm*
w2	*1.5 cm*

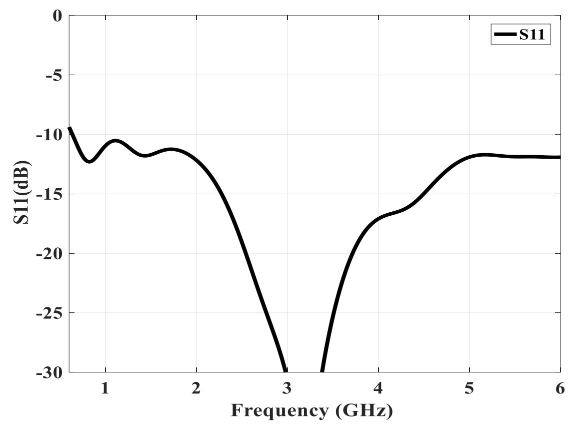


Fig. 5 Simulated reflection coefficient of the Bow-Tie Blade Monopole antenna

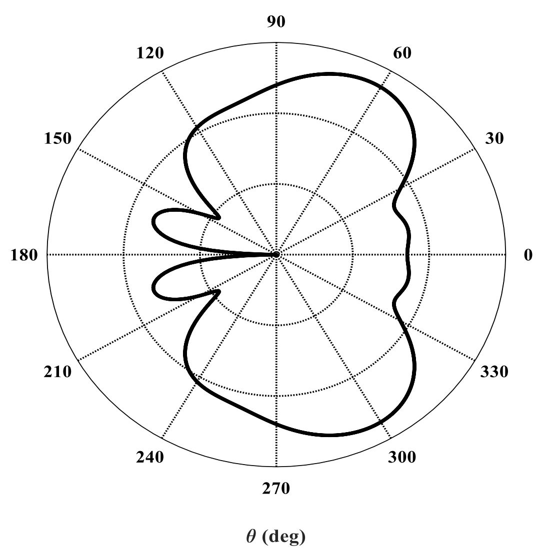
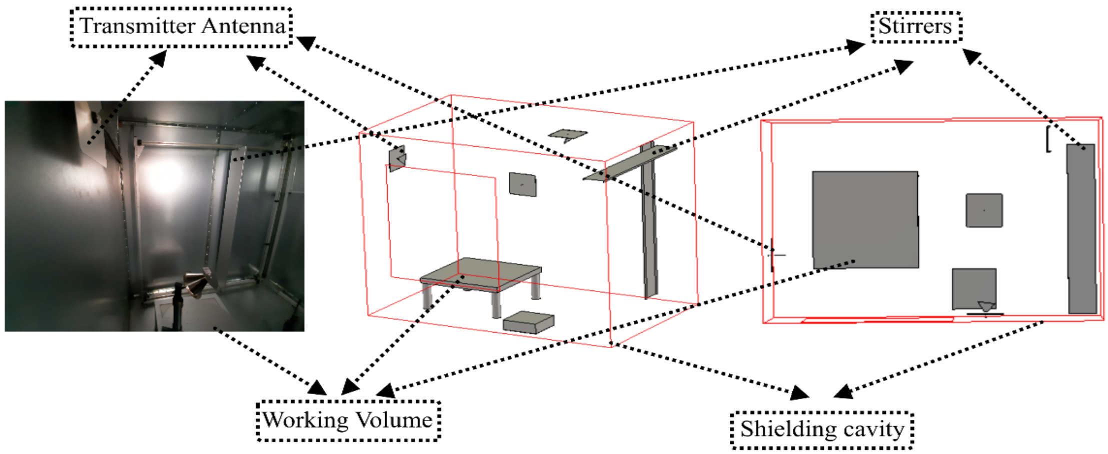


Fig. 6 Simulated radiation pattern of Bow-Tie Blade Monopole Antenna in elevation plane (f= 3 GHz)

The considered RTS60 room has two stirrer blades, one of them moves horizontally and the other one moves vertically. In Fig. 7 the location of these stirrers inside the chambers is shown.



a) b) c)

Fig. 7 RTS60 component a) inside component of actual RTS60 b) 3D view of modeling in CST c) upper view of modeling in CST

The location where the table with the dimension of *0.604m × 0.604m* and height of *30 cm* is placed, defines the working volume of the RTS60. This table is able to turns continuously during the tests so that the distribution of electromagnetic waves, affecting all parts of the device under test, becomes statistically uniform.

In order to illustrate the distribution of electric field inside the RTS60, the simulated electrical field intensity inside the chamber is shown in Fig. 8. In this simulation, all of the chamber antennas have been excited simultaneously and equally.

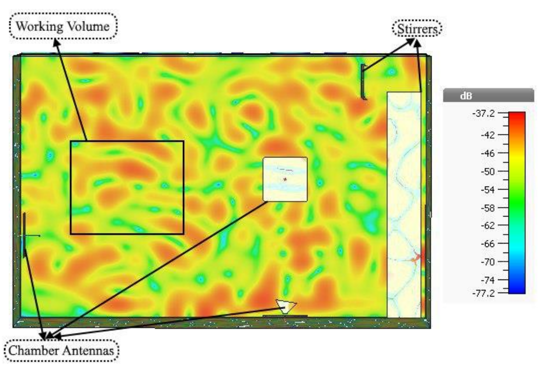


Fig. 8 The electrical field intensity inside the RTS60, simulated in CST (1.5 GHz)

In order to measure the electric field around the table according to IEC 61000-4-21, eight electric field probes at two different heights and at four corners of the table are placed, in accordance with Fig. 9 .The results demonstrate the field uniformity at each point of the table.

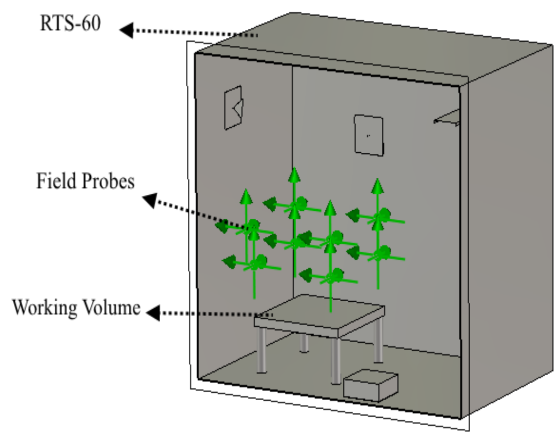


Fig. 9 Location of probes in WV modeled in CST

5- Test Procedure and Results

To measure the SD parameter of this reverberation chamber, the method, introduced in [16], is used. The measurement is performed at the frequency list, which is logarithmically opted based on the method mentioned in section III. For each frequency point, all three antennas are stimulated inside the room. Field probes at each direction individually measure the electric fields produced by each antenna. In the first step, the maximum electric fields of each antenna are obtained separately for each probe location and each particular direction, called Em.n. In the next step, the average of all Em.n for each frequency is calculated and named Em×n in (3) . By placing each of these parameters in (3), the SD parameter is obtained for a given frequency and a specific direction. This process is repeated for each direction and all frequency points. The stirrer is the main component of the Reverberation chamber, which determines the statistical uniformity of the field. The shape, dimensions and the number of stirrers are important parameters that affect the uniformity of the field [17]. To investigate the stirrer effects on the field uniformity, they are initially removed from another simulation and the field uniformity parameter, SD, is obtained again. The results, shown in Fig. 10, demonstrates that by removing the stirrers, the field uniformity inside the RC is deteriorated. As can be seen, the SD goes above 3dB in many frequency points.

Then, the stirrers are added to the simulation. As the field uniformity must be maintained during the movement of stirrers, the SD parameter is checked at different stirrer locations. Ideally, infinitely different locations should be considered for the stirrers to ensure uniformity of field, which is extremely time-consuming. However, due to the electrically large volume of the simulation, we have only obtained the SD parameter in three different locations of stirrers in this work. Full wave Simulation of each position of the stirrers takes four days by using a computer with 64GB of RAMs and core i7 2.4GHz CPU. In the Fig. 11, these three locations of stirrers are shown.

In the Figs. 12-14, the SD parameter of the chamber is given, respectively for three all positions, P1, P2, P3. As shown in these diagrams, the SD value in the frequency range of 600 to 6000 MHz is below the threshold of the IEC 61000-4-21standard, which is almost 3 dB. This verifies that the field uniformity in the working volume of the chamber becomes acceptable with the presence of the stirrers in every position.

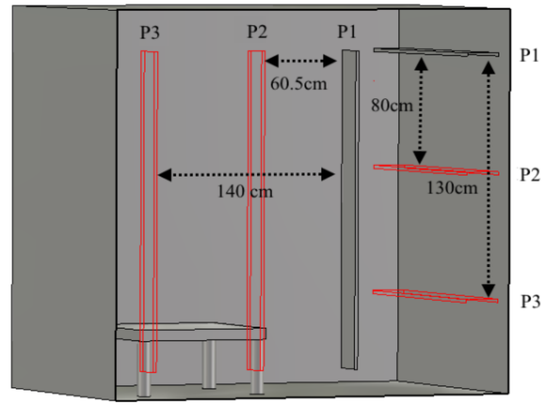


Fig. 10 Three different position of stirrers modeled in CST

In order to ensure the performance of the RTS60 chamber, as well as to verify the simulation results, a set of measurements have performed by putting a field probe inside the chamber. As shown in Fig. 15 the measurements that are performed on the absolute value of SD parameter in this frequency range confirming that the RST60's SD is below the 3dB level set by the standard. The measurement setup consists of a signal generator and a Narda NBM-550 probe is shown in Fig. 16. The probe has a directional sensor that can measure electric field from 3 MHz to 18 GHz with a precision of 1μV. Since the working frequency of the signal generator is limited to 3 GHz, the measurement is performed up to this frequency. The result diagram also makes it clear that the simulated and measured results are agreement. The difference between the practical and the simulation results shown in Fig. 15 Is due to the small details of the low impact those are not included in the chamber modeling.

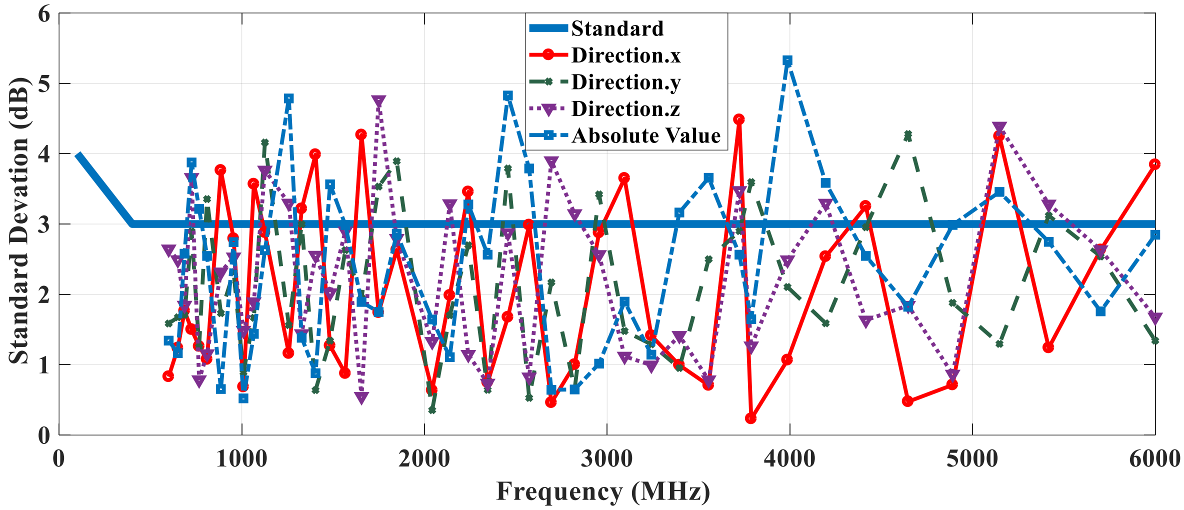


Fig. 11 Four different calculated SD based on simulation results for RC without stirrers

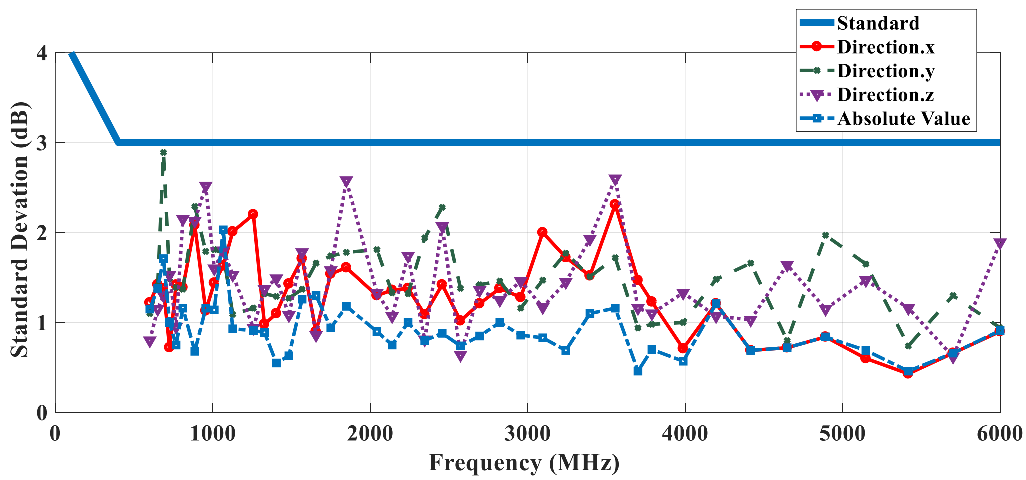


Fig. 12 Four different calculated SDs based on simulation results for the stirrer location *P1*

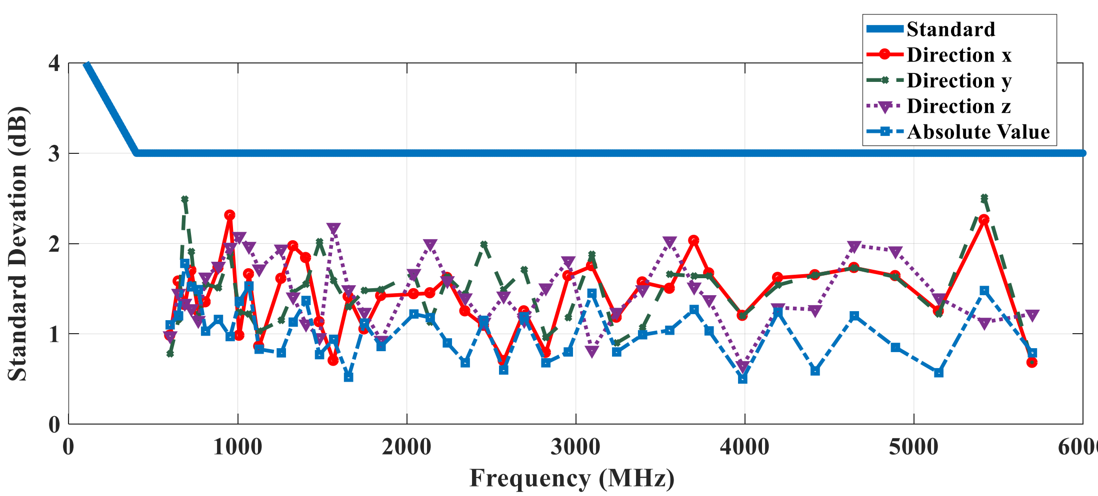


Fig. 13 Four different calculated SDs based on simulation results for the stirrer location *P2*

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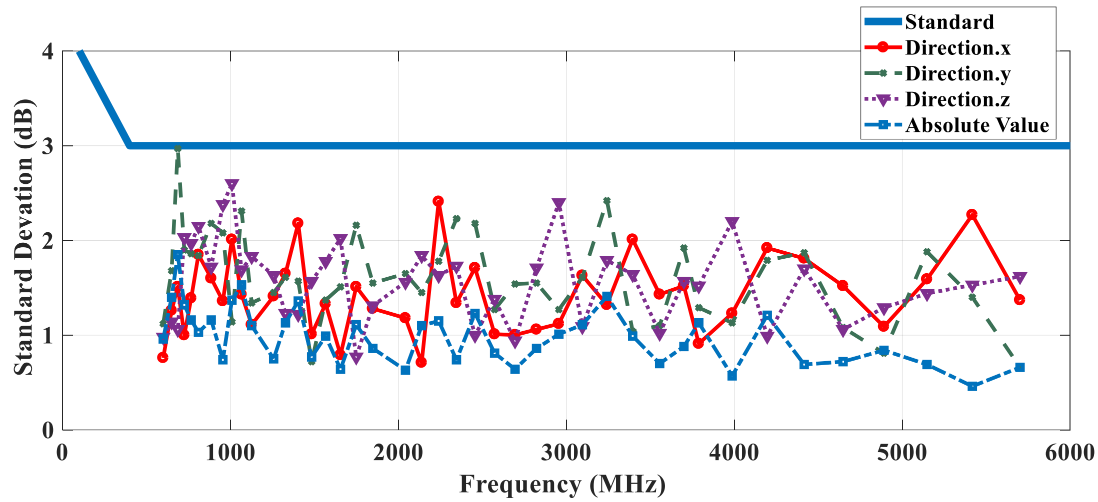

Fig. 14 Four different calculated SDs based on simulation results for the stirrer location *P3*

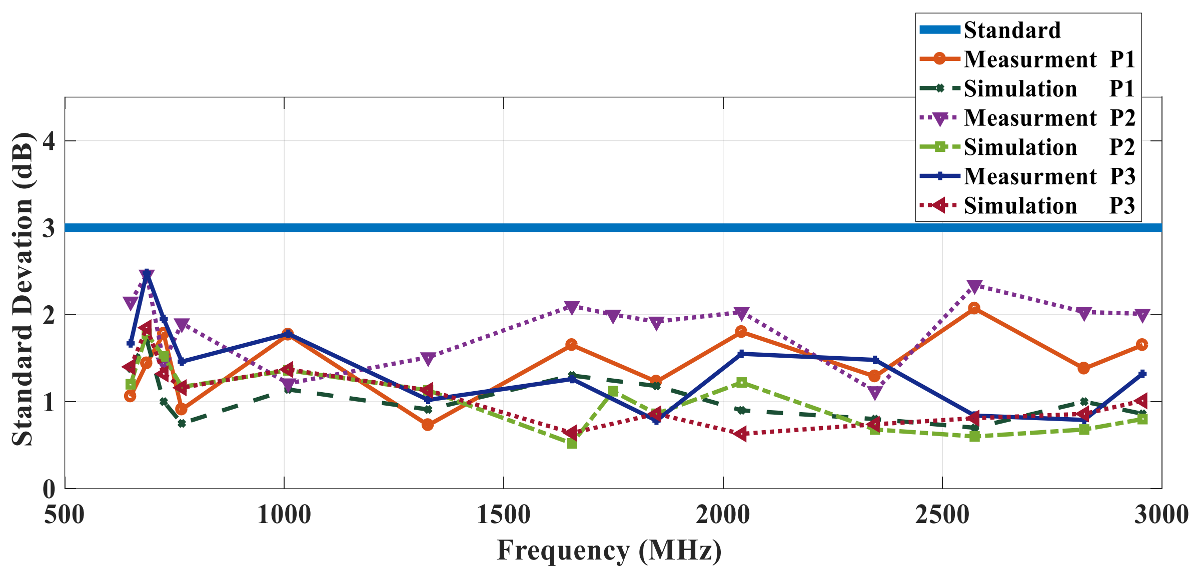

Fig. 15 Calculated absolute value of SD based on measured and simulated results for all three locations, *P1*, *P2* and *P3*

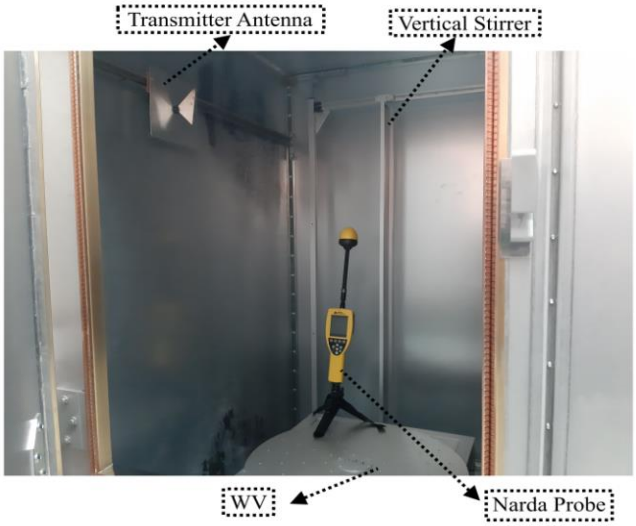

Fig. 16 Electrical field measurement by probe NBM-550, placed inside RTS60

6- Conclusion

In this paper, the field uniformity of a real reverberation chamber (RC), RTS60, has been investigated. As the main feature of real reverberations, the Standard Deviation (SD) of the chamber has been theoretically discussed, simulated and then practically verified. It is also confirmed the stirrers has a crucial role in making the electric field uniform. The simulated and measured results validates that the field distribution within the working volume of the RTS60 is better than the level set by the IEC 61000-4-21 standards.

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