FDTD simulation of field performance in reverberation chamber excited by two excitation antennas

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Abstract. The excitation source is one of the critical items that determine the electromagnetic fields in a reverberation chamber (RC). In order to optimize the electromagnetic fields performance, a new method of exciting RC with two antennas is proposed based on theoretical analysis. The full 3D simulation of RC is carried out by the finite difference time domain (FDTD) method on two excitation conditions of one antenna and two antennas. The broadband response of RC is obtained by fast Fourier transformation (FFT) after only one simulation. Numerical data show that the field uniformity in the test space is improved on the condition of two transmitting antennas while the normalized electric fields decreased slightly compared to the one antenna condition. It is straightforward to recognize that two antennas excitation can reduce the demands on power amplifier as the total input power is split among the two antennas, and consequently the cost of electromagnetic compatibility (EMC) test in large-scale RC can be reduced.

1. Introduction
Reverberation chamber is a new EMC test environment which has the evident advantages of higher quality factor (Q), lower test cost and bigger test space over the traditional test fields. The three-dimensional full simulation of reverberation chamber (RC) plays an important role in RC’s design and its performance optimization. This simulation can be divided into two categories, frequency-domain and time-domain simulation. Since long time and big computational resource is called for the simulation running for one time, time-domain simulation is preferred because of wideband response of RC could be obtained using FFT in the post-stage. The finite difference time domain (FDTD) method has been used widely in numerical simulation of RC in recent years [1, 2].

The electric field (E-field) strength and field uniformity within test space are the key parameters in RC’s performance validation. From theoretical analysis, one can see that the electromagnetic fields are related to the RC’s geometry, working frequency and the feeding source. Towards the improvement of field uniformity, much work has been done focusing on the optimization of RC’s geometry including the stirrer’s structure and the RC’s wall dimensions [3-5]. However, the reports on the effect of feeding source on field uniformity or field strength are found to be scarce, especially on the condition of two excitation antennas. To extend the previous work [6], the effect of two excitation antennas on the RC’s field performance is investigated in wide frequency band using FDTD.

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The full 3D simulation of RC is carried out by FDTD on both excitation conditions of one antenna and two antennas. The broadband response of RC is obtained after only one simulation by FFT. Numerical results show that using two excitation antennas could help improve the field uniformity and reduce the demands on power amplifier as the total input power is split. Consequently, the cost of EMC test in large-scale RC can be reduced.

2. Effect of excitation source on E-fields

Based on the Maxwell’s equations, the expression of electric fields inside a RC can be deduced using eigenfunction superposition method [7].

\[ \vec{E} = \sum_{m,n,p} (c_{x,mnp} A \hat{e}_x + c_{y,mnp} B \hat{e}_y + c_{z,mnp} C \hat{e}_z) \]

where \( \vec{E} \) is the E-field strength vector, \( \hat{e}_x, \hat{e}_y, \hat{e}_z \) and \( \hat{e}_z \) are unit vector point to the x, y, z direction, \( mnp \) corresponds to a resonant mode of the RC, \( A, B, C \) are Eigen solutions related to the x, y, z component of E-field respectively and the weighting coefficients are given by

\[ c_{x,mnp} = \frac{c^2}{4\pi^2 (f^2 - f_{mnp}^2) LWH} \int_{\Omega} \omega \mu_0 J_x A dxdydz \]
\[ c_{y,mnp} = \frac{c^2}{4\pi^2 (f^2 - f_{mnp}^2) LWH} \int_{\Omega} \omega \mu_0 J_y B dxdydz \]
\[ c_{z,mnp} = \frac{c^2}{4\pi^2 (f^2 - f_{mnp}^2) LWH} \int_{\Omega} \omega \mu_0 J_z C dxdydz \]

where \( c \) is the speed of light in vacuum, \( \omega \) is angular frequency, \( \mu_0 \) is the permeability of vacuum, \( f \) is the RC’s working frequency, \( f_{mnp} \) is the resonant frequency, \( L, W, H \) are dimensions of the RC, and \( J_x, J_y, J_z \) are the excitation currents density in the corresponding directions.

According to (1)(2), the E-fields mainly depend on three factors: the RC’s geometry, the working frequency \( f \) and detailed configuration of the feeding source including its position in the RC and the specification of the driving current. It is well known that mechanical stirrers can help realize field uniformity by changing the boundary conditions which is equivalent to the first factor. So considering the third factor, it is assumed to be beneficial to field uniformity to apply two excitation antennas since the weighting coefficients are related to the excitation source. When putting the excitation antennas at different positions with typical directions, the electromagnetic fields from each transmitting antenna are superimposed randomly ending up with the field uniformity improvement within the test space. This assumption is supported by the following numerical simulation data.

3. RC’s modelling and numerical simulation by FDTD

The studied mode-stirred RC has dimensions equal to 8m×10.5m×4.3m and the stirrers are similar to that in [8] but a little more irregular. An efficient discretization method [9] is applied to model the stirrers making the two stirrers rotate independently with a random rotating degree. As the fundamental mode frequency is 23.6 MHz, the most interesting frequency band for this RC could be chosen as 60 MHz to 300MHz according to [10]. In accordance with the FDTD principles defined in [11], the space and time increment are set equal to \( \Delta h = 0.1 \) m (the space step is the same for the three dimensions) and \( \Delta t = 1.67 \times 10^{-10} \) s with the Courant factor being \( \sqrt{3}/2 \). The RC is excited by dipole antennas which are modeled using the thin-wire technique [12, 13]. At the middle port, the dipole antenna is attached to a transmission line (TML) with the characteristic impedance being \( Z_0 = 50 \) \( \Omega \). A unit-amplitude modulated Gaussian pulse defined by the frequency range from 60MHz to 300MHz is applied into the TML as incident voltage source \( v_{inc} \) and the reflected voltage \( v_{ref} \) in time domain
could be recorded as discussed in [14]. This kind of feeding method is convenient to calculate the input power $P_{inp}$ of the excitation antenna.

$$P_{inp} = \frac{|\tilde{V}_{inc}|^2}{Z_0} - \frac{|\tilde{V}_{ref}|^2}{Z_0}.$$  \hspace{1cm} (3)

where the $\tilde{V}_{inc}$ and $\tilde{V}_{ref}$ are the frequency components related to $v_{inc}$ and $v_{ref}$ respectively. The RC’s geometry and the antennas’ configuration are showed in Figure 1. The TML is in dotted lines indicating that its real structure is not included in the 3D full simulation but is solved by additional one-dimension FDTD codes.

![Figure 1. Schema of the RC’s structure.](image)

Disposal of loss is of great importance to the RC’s simulation in time domain since the simulation should be running until the total energy inside decreases small enough. We adopt an approximation method by setting the electric conductivity of the air within the RC to $10^{-3}$ S/m while treating the RC as PEC structure according to [15]. In order to verify the conclusion from the end of section 2, the simulation is carried out on two excitation conditions of one antenna and two antennas, which is achieved by removing antenna #2 or not. A test volume $(5 \times 3 \times 2.3m^3)$ is chosen as referred to the IEC-61000-4-21 standard. The eight vertices of this volume are chosen as the observation points for the field uniformity verification.

On each excitation condition, the stirrers are rotated in an interleaved way with the rotation step being 45 degrees. 64 different stirrers’ configurations are obtained satisfying the specification in IEC-61000-4-21 standard. FDTD codes for every stirrer configuration are created and executed separately. Each execution is taken 50000 iterations and the E-field amplitude in RC decreases below $1/100$ of its peak value.

4. Simulation results and discussion

All three orthogonal components of E-field at each of the eight vertices are recorded during the execution of RC’s FDTD code. The corresponding frequency values $\tilde{E}_{i,j} , i = x, y, z , j = 1,2...8$, are obtained by FFT with the frequency resolution being $1/\Delta t / 50000 = 120$ KHz. The normalized E-field $E_{nor}^{i,j}$ is computed by

$$E_{nor}^{i,j} = \frac{\tilde{E}_{i,j}}{\sqrt{P_{inp}}} \hspace{1cm} i = x, y, z, j = 1, 2...8.$$  \hspace{1cm} (4)
At each observation point, for every orthogonal component of E-field, the maximal value occurred during a complete rotation of stirrers is selected and they are used to compute the standard deviations of the E-field in dB according to IEC-61000-4-21 standard.

4.1. Investigation into the field uniformity

There are four parameters $\sigma_x, \sigma_y, \sigma_z$, and $\sigma_{24}$ embodying the standard deviations of E-fields which should not exceed a limit specified by IEC-61000-4-21 standard. From the theoretic analysis in section 2, it is possible to improve the field uniformity using two transmitting antennas.

Using the E-field vector data on eight vertices in frequency domain, the four parameter $\sigma_x, \sigma_y, \sigma_z$, and $\sigma_{24}$ in dB on both conditions are computed by reference formulas in [16]. Glancing at the results showed from Figure 2 to Figure 5, we can see that the field uniformity satisfies the standard specification on both exciting conditions above 70MHz. These four figures are similar to each other, and the fourth exhibits less fluctuations because of its statistical components being 24. Comparing the two main lines in each figure, it is not hard to recognize that the two antennas excitation method can help improve the field uniformity at most of the studied frequency points.

In order to see this improvement more explicitly, a statistical parameter $\eta$ called improvement degree is proposed.

$$\eta = \frac{\langle \sigma^y \rangle - \langle \sigma^n \rangle}{\langle \sigma^n \rangle} \times 100\%$$

where $\sigma$ can be any of $\sigma_x, \sigma_y, \sigma_z$, or $\sigma_{24}$, the superscripts ‘$\text{'}$‘ and ”$n$“ stand for one antenna and two antennas excitation conditions, and $\langle \rangle$ denotes the mean value in a specified frequency band.
Table 1. Improvement degree of E-field standard deviation in separated frequency bands.

| Std. dev. \freq. bands | 60~120MHz | 120~180MHz | 180~240MHz | 240~300MHz |
|------------------------|-----------|------------|------------|------------|
| $\sigma_x$             | 5.05 %    | 5.43 %     | 0.23 %     | 2.03 %     |
| $\sigma_y$             | 2.94 %    | 3.87 %     | 3.63 %     | 1.23 %     |
| $\sigma_z$             | 7.86 %    | 3.48 %     | 1.54 %     | 4.49 %     |
| $\sigma_{24}$          | 3.36 %    | 1.88 %     | -0.94 %    | 0.98 %     |

The studied frequency band is divided into four groups, and the corresponding $\eta$ is displayed in Table 1. The results indicate that the two antennas excitation method can achieve an average field uniformity improvement in all the four frequency bands for all the uniformity parameters except $\sigma_{24}$ within 180~240 MHz. This improvement is more obvious when the frequency is below 180 MHz, which can be explained by the well-known trend that the field uniformity gets better naturally as the frequency increases.

4.2. Comparison of normalized E-fields.

The normalized E-field modulus at vertex #1 is compute from the maximum E-field over the rotation of stirrers. Figure 6 shows that the normalized E-field modulus on condition of two transmitting antennas is slightly smaller than that of one antenna condition, especially when the frequency is below 150 MHz. Besides vertex #1, we can see from Figure that the E-field strength is also smaller at other vertices at the frequency of 200 MHz. There may be two reasons for this phenomenon, one is that the coupling between the two antennas adds additional losses to the RC’s overall losses, the other is that the field uniformity’s improvement on the two antennas condition may be realized by decreasing the maximal E-field strength and increasing the minimal E-field strength, whereas the reference quantity is the maximal E-field strength but not the average value.

4.3. Exploration of exciting a large RC by two antennas

In the engineer application, two advantages make it attractive to apply the new excitation method to large-scale RC. On one hand, it is instrumental in producing a reverberation environment in a large RC; on the other hand, it can save on the cost of power amplifier without the deterioration of field uniformity.
If the dimensions of the RC are very large, the electromagnetic field decreases obviously as its location moves away from the excitation antenna. Consequently, only one transmitting antenna can hardly generate statistical uniform electromagnetic field. Using two or more excitation antennas located at different positions with different orientations inside the RC will alleviate the non-uniformity distribution of electromagnetic energy. In this way, the new excitation method is helpful in producing a reverberation environment. In addition, the price of high-power amplifier is usually much larger than twice of the ordinary power amplifier’s price. In this way, it is a good alternative to apply the new excitation method to generate high-intensity electromagnetic field if using one power amplifier is not economically acceptable.

5. Conclusion
A new excitation method is proposed using two transmitting antennas for reverberation chamber. The two antennas should be put at different position with different orientations. From the above comparison and analysis, this method can lead to a slight improvement on field uniformity and slightly lower normalized E-fields than the traditional method. More importantly, this method could reduce the demands on power amplifier without the deterioration of field uniformity. So it can be used to generate high E-field in RC for special equipments’ EMC tests.

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