The Effect of Two Stirrers in a Large Reverberation Chamber

Wang Sheng, Zhang Daming, Yuan Weiliang, Wang Baikuan
Institute of High Performance Computing, EMC Division
89C, Science Park Drive, #02-11/12, The Rutherford, Singapore 118261
E-mail: wangs@ihpc.nus.edu.sg

Abstract: The significant characteristics of the electromagnetic environment in an ideal reverberation chamber are uniformity, isotropy and random polarization. Stirrer performance in a reverberation chamber is crucial to these characteristics. In this paper, based on the statistical theory, the uncertainty due to the number of independent samples is given. The key mechanism that causes the fields in a reverberation chamber to become uniformly random by rotation of stirrers, and the advantages of using two stirrers over one stirrer are analysed. The E-fields inside a large reverberation chamber with two stirrers and with one stirrer respectively are simulated using the Finite-Difference Time-Domain (FDTD) technique. By comparing the effects of two stirrers with that of one stirrer on the uniformity and number of independent samples, it is found that two stirrers produce a better performance in a large reverberation chamber than one stirrer with a relatively larger size.
Keywords: Reverberation chamber, Stirrer, Electromagnetic environment

1. Introduction

A reverberation chamber is an electrically large metal room with one or more rotating conductive stirrers. A properly designed and operated reverberation chamber will provide a test electromagnetic environment (EME) that is statistically homogeneous and isotropic. The test EME is obtained by sufficiently sampling of independent, complex cavity boundary conditions [1-3]. For immunity testing, the maximum field must be quantified by using the extreme value theory [4], which also needs a large number of independent samples. So the number of independent samples plays an important role on the uncertainty within certain confidence limits of EME. By rotating the metal stirrers through different positions in a reverberation chamber, a large number of independent samples are obtained. The idea is to perturb the boundary conditions to modify the eigenmode of the modes present in the reverberation chamber. Earlier work [5] has pointed out that small stirrers are by no means appropriate since they can not modify the modes great enough to introduce randomness, and only large stirrers are effective. However, with the increasing size of stirrers, it places great demands on the driver motor and controller system. It is expected that by introducing two or more stirrers with relatively smaller sizes, they can produce the performance that can match or even be better than a single stirrer with larger size.

In this paper, firstly, the relation between the number of independent samples and the desired accuracy is studied. Secondly, the effects of stirrers are analysed. Finally, the simulation results of two stirrers and one stirrer in a large reverberation chamber with dimensions of 12.5m×8.5m×6m are compared.

2. Requirement on independent samples

Numerous papers have discussed the expected distribution functions for the statistical EME in a properly designed and operated chamber. The received power density for one dimensional field component (E_x, E_y or E_z) is proportional to the square of the field, and is exponentially distributed. The probability distribution function is

$$f(p) = \frac{1}{2\sigma^2} e^{-p/2\sigma^2} \qquad (1)$$

where

$$\sigma^2 = \left\langle E_x{}^2 \right\rangle / 2 = \left\langle E_y{}^2 \right\rangle = \left\langle E_z{}^2 \right\rangle$$

For a large sample number, σ^2 is approximately normally distributed. The normalized accuracy of σ^2 is $1/\sqrt{N}$ for one-dimensional data. The normalized accuracy of σ^2 makes it possible to determine how many samples are needed for a desired accuracy. The probability that is within k standard deviation of its mean (σ^2) is [6]

$$prob[\sigma^2 - k \cdot \frac{\sigma^2}{\sqrt{N}} < \sigma^2 < \sigma^2 + k \cdot \frac{\sigma^2}{\sqrt{N}}] = \frac{2}{\sqrt{2\pi}} \int_0^k e^{-y^2/2} dy \qquad (2)$$

For σ^2 is within a confidence interval of ddB, the required independent number of the field data is

$$N = k^2 \cdot \left(\frac{10^{d/10} + 1}{10^{d/10} - 1}\right)^2 \qquad (3)$$

Fig.1 is the plot of standard deviation k as a function of independent sample number N when $d = 1dB$. With $k = 90\%$, N is required to be no less than 206; $k = 95\%$, N is no less than 293.

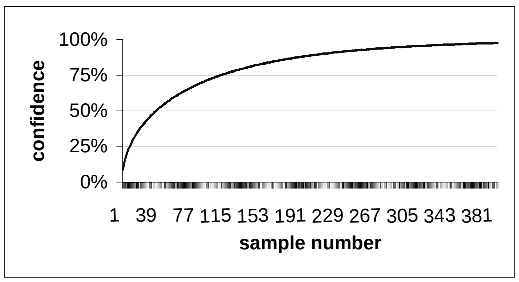

Fig. 1

For an immunity test, in most cases, the peak value of the EME will be of more interest than the mean value. By using the extreme value theory, it is possible to write the probability density function of the maximum of these samples. Using $\lceil E_i \rceil_N$ to indicate the maximum of N independent E_i samples, the mean and variance of $E_i{}^2$ are presented as below:

$$\lceil x_2^2 \rceil_N \approx 2\sigma^2 (0.577 + \ln(N) + \frac{1}{2N}) \qquad (4)$$

$$\mathrm{var}\left\langle \lceil x_x^2 \rceil_N \right\rangle \approx 4\sigma^4 (\frac{\pi^2}{6} - \frac{1}{N}) \qquad (5)$$

Thus the ratio of the mean of $\lfloor E_i^2 \rfloor_N$ to the mean of E_i^2 is derived as below:

$$r = 0.577 + \ln(N) + \frac{1}{2N} \qquad (6)$$

r is a good estimator of the maximum to the average ratio.

The uncertainty can be described as below:

$$k_{err} = \frac{2\sigma^2 \left[\frac{\pi^2}{6} - \frac{1}{N} \right]}{\left[0.577 + \ln(N) + \frac{1}{2N} \right]} \qquad (7)$$

This means that in order to estimate the largest measured value by the mean value within certain error limit, for uncertainty to be within 1dB, N .is required to be larger than 200.

From above discussion, the conclusion can be drawn that a large number of independent samples is required to ensure that: (1) the pdf for one dimensional field square is chi-square distribution;and (2) the measured peak is close to the true peak.

3. The effect of stirrers

In order to get enough independent samples in a reverberation chamber, the design of stirrers is crutial. The factors that govern the effectiveness of the stirrers must be known to gain insights on the design of stirrers. Without stirrers, the spatial variation of the field in an empty cavity can be as high as 40dB. In order to perturb the non-random nature of the incident field, we seek to maximize the scattered field, which is induced by stirrers. These perturbed mode functions differ from the unperturbed mode functions in that they satisfy the boundary conditions on the perturbing body surface as well as on the cavity walls. The boundary conditions can be changed by two ways: (1) change the position of large stirrers; or (2) change the location of large stirrers. Since it is hard to move the stirrers, randomness is introduced by rotating the large stirrers. It is expected that when a large stirrer rotating, the amount of shift for each mode will be large enough that randomness is introduced into the cavity. As mentioned before, in order to satisfy the requirement of the uncertainty within $1\,dB$ with 90% confidence limit, the number of independent samples should be no less than 206. Here let N =206, then the angular interval $\Delta\theta$ of a rotating stirrer should be 1.8°. Since the samples must be independent, the boundary conditions should change enough to shift the eigenmodes when the stirrer rotates 1.8°. For one stirrer, there is only one way to reach this requirement, that is increasing the size of the stirrer until the modes are quite sensitive to the location of stirrer. It can be postulated that when two stirrers are used in the chamber to get enough number of independent samples, the stirrers may be smaller than one single stirrer. Since one stirrer can rotate in the 1.8° interval, and it need not to be independent in two positions while another stirrer rotates in an independent interval, the resultant $\overline{E}$ field is independent under the combined effects of the two stirrers. However, it should be pointed out that though the combination of two smaller stirrers can be used to enhance the stirrer effectiveness, they must have the minimum size required for effective stirring. If the stirrers are too small, regardless of how they are being rotated, they can never produce a spatially uniform field.

4. Simulation

4.1 Autocorrelation function

For a small change in the stirrer position, it is expected only small changes resulted in measured values. This effect will be pronounced at low frequencies where a small change in the stirrer position results in a small change in the boundary condition compared to the relative large wavelength. The field in the chamber changes significantly only when the stirrer turned by a degree θ large enough. In this paper, the E-field autocorrelation coefficient is used to evaluate the independence of two stirrer positions, which is denoted as [7]:

$$\rho_{E_{x1}E_{x2}}(r) = \frac{E_{x1}(r) \bullet E_{x2}^{*}(r)}{|E_{x1}(r)| \cdot |E_{x2}(r)|} \qquad (8)$$

When $\rho(r)$ drops to 1/e, the data is taken as independent, or in another word, θ is large enough.

4.2 Selection of stirrer positions and number of stirrer step

Since the stirrer positions play an important role in the generation of EME, attention should be put on it. For the case of two stirrers, the choice of stirrer locations is more difficult. We must choose an algorithm for moving two stirrers that can take advantage of the effect of two stirrers. In order to get enough independent samples, let one stirrer steps in a small increment and the other stirrer steps in a large increment. Here choose one stirrer in steps of 360/N, the other stirrer in steps of $360/\sqrt{N}$. .Since it has been calculated earlier, N should be no less than 206, the small step $\Delta\theta_1$ is chosen as 1.8°, the large step $\Delta\theta_2$ is 25°.

4.3 Results

A 3-dimensional model of a reverberation chamber with dimension 12.5m×8.5m×6m with two Z-shaped stirrers inside is generated using FDTD. The dimensions of the two stirrers are 2.5m×4m and 3m×5m respectively. The excited frequency is 80MHz. In order to evaluate the advantage of two stirrers over one stirrer, the same chamber with one stirrer of 4m×6m is simulated. The autocorrelation coefficients are calculated for one stirrer and two stirrers respectively. It is noted that for the one stirrer model the E-field becomes uncorrelated after 3 steps, or 5.4°, which means only 70 independent samples can be gotten. It is not statically sufficient for the analysis to be valid. For the case of two stirrers, it becomes uncorrelated after one step, or 1.8°, which means all the 206 samples are independent. This is just as we expected. The x-component mean amplitude of the electric field at 16 points in defined working volume for one stirrer and two stirrers are given in Fig.2 and Fig.3. In the figures, the maximum differences are 4dB and 2.3dB.respectively. Apparently, two stirrers produce a much better uniform electric field in the defined uniformity volume.

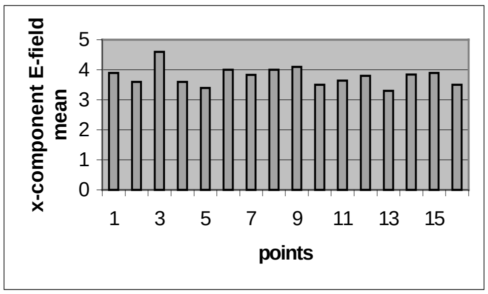

Fig.2 The simulation result of one stirrer

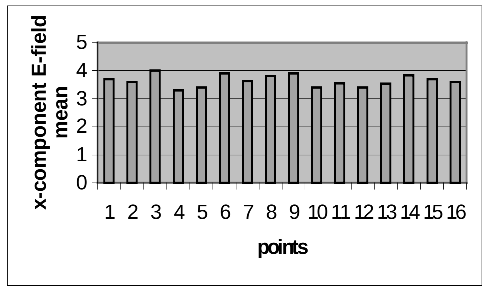

Fig. 3 The simulation result of two stirrers

5. Conclusion

The primary objective of this study is to investigate the advantages of two stirrers over one stirrer in a large reverberation chamber. Based on statistics theory, the relation between the uncertainty within a definite confidence limit and the number of independent sample is derived. It is noted that in order to obtain a homogeneous test EME and reliable peak value, the number of independent samples should be no less than 206. Through theory analysis, it is found that a chamber with two correctly designed stirrers is easier to reach this requirement than that with one stirrer of a relatively larger dimension, and two stirrers will produce the better performance than one stirrer. The simulation results of a large reverberation chamber with two stirrers and one stirrer respectively agree well with the theory analysis.

6. References

[1] M.L. Crawford and G.H. Koepke Design, evaluation and use of a reverberation chamber for performing electromagnetic susceptibility/vulnerability measurement. NBS technical Note 1092, National Bureau of Standards, April 1986.

[2] D.A. Hill Electromagnetic theory of reverberation chambers. NIST Technical Note 1506, December 1998.

[3] T.H. Lehman A statistical theory of electromagnetic fields in complex cavities. EMP Interaction Note 494, May 1993.

[4] P.A. Probabiility Random variables, and stochastic processes. New York, McGraw-Hill Book Company, 1984.

[5] D.I. Wu. The effect of an electrically large stirrer in a mode-stirred chamber. IEEE Trans. Electromagnetic compatibility, Vol 31, May 1989, pp. 164-169.

[6] J.G. Kostas and B. Boverie Statistical model for a mode-stirred chamber. IEEE Trans. Electromagnetic compatibility, Vol 33, November 1991, pp. 366-370

[7] D.A. Hill Spatial Correlation Function for Fields in a Reverberation Chamber. IEEE Trans. Electromagnetic Compatability, Vol 37, February 1995, pp. 138