A Study of the Field Statistics in Nested Frequency-Stirred Reverberation Chambers

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Abstract

This paper describes the underlying statistics of the field in nested frequency-stirred reverberation chambers. The hypothesis of the probability distribution function (PDF) of a component of the frequency-stirred electric field ($E_{\mathrm{Re}c}$) is provided and then examined by a number of goodness of fit tests. The results show that for an electrically large enclosure nested in a larger reverberation chamber, the PDF of the internal electric field $E_{\mathrm{Re}c}$ will evolve from Rayleigh to double Rayleigh with the shrinking size of the interconnection apertures. This has implications for immunity measurements of electronic systems housed in shielding enclosures.

1. Introduction

The reverberation chamber continues to attract attention in the Electromagnetic Compatibility (EMC) community due to its statistically uniform field characteristics and isotropic average incident field. The PDF of the magnitude of one component of the electric field $E_{\mathrm{Re}c}$ in a well-stirred reverberation chamber is characterized by a Rayleigh distribution [1][2]. However in practical applications, Equipments under Test (EUT) need to be placed in a reverberation chamber to be illuminated by the internal field. Especially for the shielding effectiveness and the immunity tests [3][4], the EUT is either an enclosure or is contained within an external enclosure; this arrangement effectively forms a so-called nested chambers system, where two cavities are connected by a number of intentional or unintentional apertures on the equipment enclosure. Mechanical stirring or frequency stirring is usually used in order to achieve the wanted statistical field homogeneity. For the nested chambers system, frequency stirring is preferred as it can be easily implemented by shifting the measuring frequency in a designated bandwidth, in contrast to the mechanical stirring approach, which needs to introduce extra structures, particularly difficult in an equipment enclosure. However, the statistical feature of such a frequency-stirred nested chambers system should be well researched before it can be applied. In particular, we are mostly concerned about the rectangular component of the electric field for its proposed application in measuring the shielding effectiveness [3]. The frequency-stirring field in the outer reverberation chamber should follow the Rayleigh distribution;

$$f(x) = \frac{x}{\sigma^2}\exp(-\frac{x^2}{\sigma^2}) \tag{1}$$

where σ is the scale parameter of the data. The energy induced into internal contents from this field distribution then follows the exponential distribution. Should the statistics of the fields inside the equipment enclosure deviate from Rayleigh then the exponential energy distribution is called into question with consequent implications for immunity testing of complex equipment.

When the field is penetrating from the outer chamber into the nested enclosure and the aperture connecting the two cavities is large enough, the two cavities perform as one complex cavity in terms of electromagnetic field. However, when the aperture is very small and the shielding is high, then the fields in two cavities are assumed to be independent of each other and therefore show an effect of multiplication, which results in a double-Rayleigh distribution for the inner field;

$$f(x) = \frac{x}{\sigma^2}K_0(\frac{x}{\sigma}) \tag{2}$$

where K_0 is the modified Bessel function of the second kind [5].

In this paper, we examine the assumptions about the frequency stirring field distribution in the nested chambers system using goodness of fit tests. In addition, for the transitional stage between these two extreme conditions, it is also interesting to see how the distribution changes.

2. Experimental Configuration and Results

A 0.48m×0.48m×0.12m equipment enclosure with a removable front panel was nested in the York EMC group mode-stirred chamber, which was 4.8m long, 3.2m wide and 2.2m high, as is shown in Fig.1. From the theory of the frequency stirring, the configuration of the nested chambers should be kept the same while the signal generator was sweeping a designated frequency band. For our experiments, a vector network analyzer, Agilent E5071B, was employed to do this job. The Port1 of the network analyzer was connected to a standard horn antenna, which was effective from 1GHz to 18GHz. The Port2 was connected to a monopole antenna mounted on the wall of the nested enclosure, to monitor the rectangular component of the coupled electric field $E_{\mathrm{Re}c}$. During the test, the power transmitted to the port1 was maintained at 0dBm and the system was calibrated to terminals of the antennas in order to make sure the transmitted power has the least variation in the swept frequency band. It should also be noted that the statistical distributions are based on the assumption that both cavities will be overmoded in the tested frequencies to allow efficient frequency stirring. Since there is no clearly stated criterion for usable mode condition yet, we calculated the number of modes excited and the mode density (Table 1) for each frequency and conservatively choose the center frequencies from 3GHz to 8GHz with an interval of 1GHz. The sweeping bandwidth around each center frequency is 100MHz and the number of sampling points is 401. The selection of appropriate bandwidth and sampling points proved very important to the test, since we need to make sure enough modes are included as well as the sampled data are independent to each other.

Table 1

Mode number and density of 0.48m*0.48m*0.1m box								
Frequency	1G	2G	3G	4G	5G	6G	7G	8G
Number of modes	8.60	68.00	231.00	549.00	1072.00	1853.00	2942.00	4392.00
Modes/100MHz	2	10	23	41	64	92	126	164

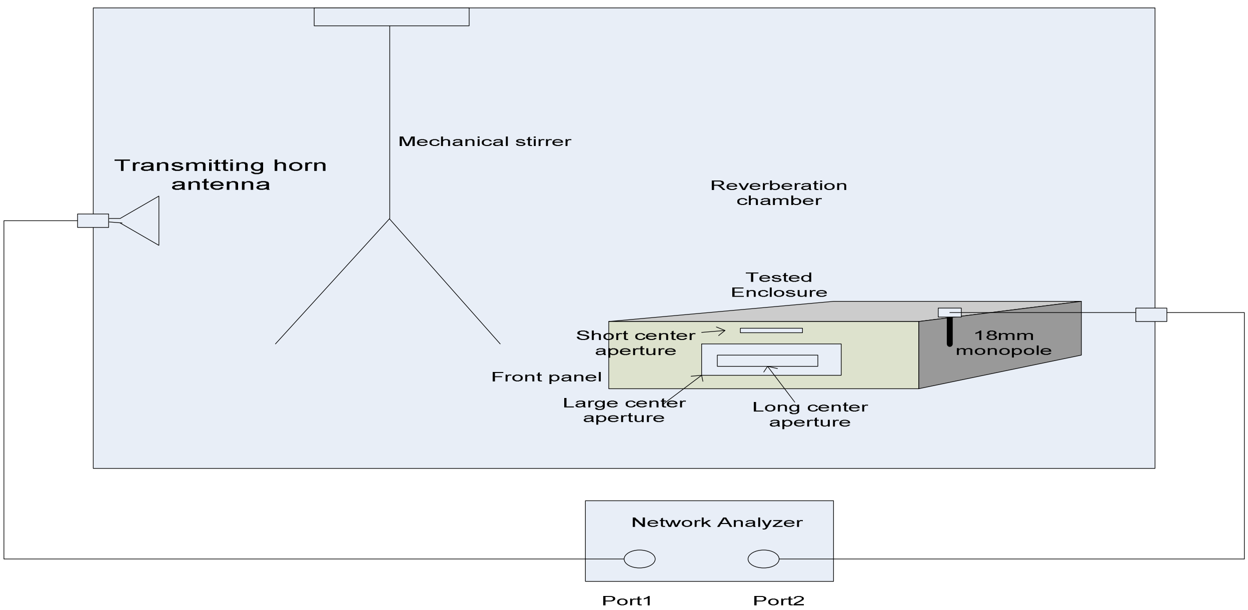


Fig.1 The experimental setup.

In order to test a field distribution hypothesis, especially for a continuous distribution, generally the Kolmogorov-Smirnov (KS) goodness of fit test is used [6]. A 5% significance level is chosen in our experiments. Furthermore, it is thought to be not convincing enough by just taking one set of sampled data and test it for the hypotheses. Here we take advantage of the mechanical stirrer in the outer reverberation chamber, as the boundary conditions of the nested chamber system will be changed when the stirrer is moving and this effectively creates a different test environment. In order to give more accurate results, *N* groups of data are collected by using *N* independent positions of the stirring paddle in the outer chamber. The KS test is then applied to each group of data and used to determine whether to accept or reject the hypothesis, H_0 , that the data is consistent with the assumed distribution. The rejection rate is defined as *m/N* when *m* in *N* groups are rejected. A value of *N* of 100 was used in this work.

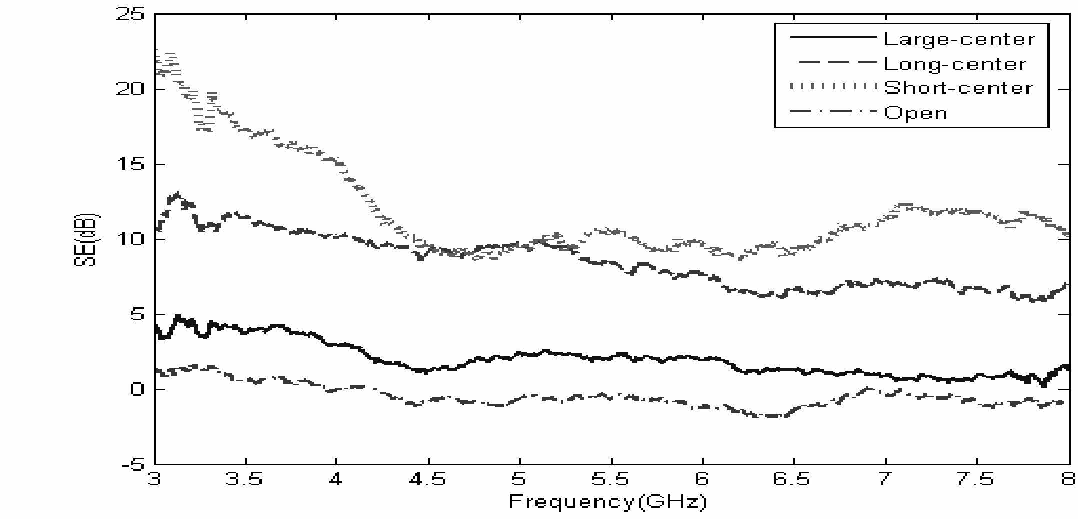
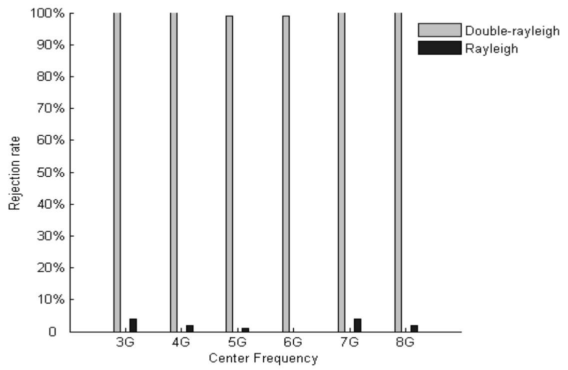
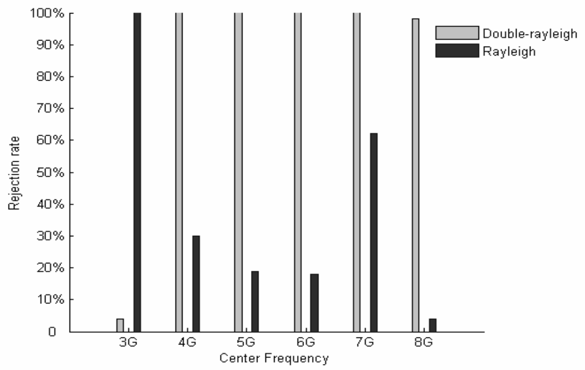


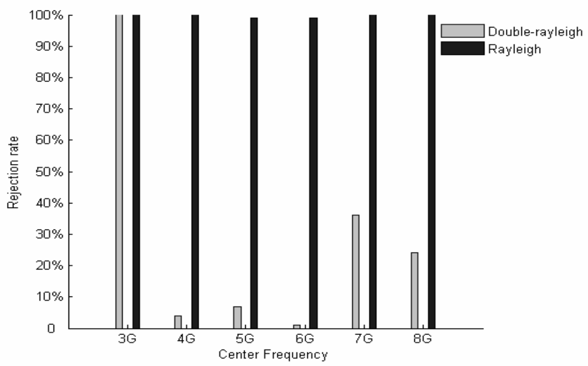
Fig.2 The shielding effectiveness increases with the shrinking size of apertures.



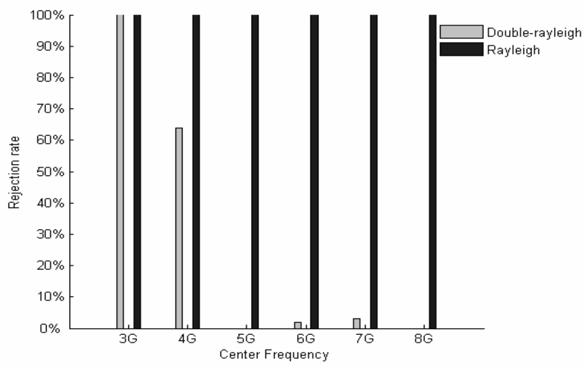
(a) ‘Open’ : The front panel is removed



(b) ‘Large_center’: 160mm*40mm aperture on the front panel



(c)‘Long_centre’: 120mm*5mm aperture on front panel



(d) ‘Short_centre’: 30mm*5mm aperture on front panel

Fig.3 Results of goodness of fit tests for 4 different apertures

As referred to above, the field distribution is hypothesized to evolve from Rayleigh (when the two cavities are connected by a large aperture) to double-Rayleigh (when the two cavities are almost isolated). Four different apertures were therefore tested: ‘Large_centre’: 160mm×40mm; ‘Long_centre’: 120mm×5mm; ‘Short_centre’: 30mm×5mm; and ‘Open’: where the front panel is totally removed. We expect the distribution will fit Rayleigh when the ‘open’ front panel is used and switch to double-Rayleigh when the ‘Short_center’ panel is employed. A shielding effectiveness test using the frequency stirring approach proposed by [3] is conducted in advance and the results are shown in Fig.2. It is apparent that the shielding effectiveness increases with the shrinking size of the apertures. Then the KS test is carried out twice on each set of data and gives the result of rejection rate to each distribution hypothesis. In Fig3, the outcomes of goodness of fit tests on both distribution hypotheses are provided. For the 'open' situation, Fig3(a), the double-Rayleigh is fully rejected in all of the frequencies whereas the Rayleigh distribution hypothesis is all accepted; this is predicted since here the nested chambers are actually one single cavity in terms of the electromagnetic field, and consequently have the same statistics as an empty reverberation chamber.

When the connecting aperture narrows down to the 'Large_centre', the double-Rayleigh hypothesis is still rejected with very high rates, however, the Rayleigh distribution seems also inappropriate as the rejection rate rises up more than 20% except at 8GHz, where the electrical size of the aperture becomes very large and consequently has the same effect as 'Open'.

For the 'Long_centre' aperture, Rayleigh turns out to be fully rejected in all frequencies. In contrast, the goodness of fit tests for double-Rayleigh hypothesis starts to show a very low rejection rate in 4GHz-6GHz; and nevertheless in other frequencies, it is still highly rejected. For 7GHz and 8GHz, it could again be attributed to the increase of the electrical size of the aperture as the wavelength becomes shorter and consequently make the inner field still correlated with the field in the outer chamber. The reason for the rejection in 3GHz is however assumed that as the modes excited in the nested enclosure are not sufficient to support the frequency stirring, this under-moded enclosure may give some unexpected results including the 3GHz in the 'Large_centre' aperture, where unfortunately exhibits a good acceptance to the double-Rayleigh distribution.

When the aperture on the front panel is changed to the 'Short_centre', the double-Rayleigh distribution fits well for most of the tested frequencies; the only exception is at 3GHz, where the frequency stirring is supposed to be not efficient. It is also noted that the rejection rate is above 60% for 4GHz; the reason is still unclear and need further research. However, this does not affect the conclusion that when the two cavities are separated well, a double-Rayleigh distribution will be manifested in the frequency stirred nested chambers. On the other hand, the Rayleigh distribution is once again rejected with a nearly 100%, which contrasts well with the 'Open' aperture.

3. Conclusion

Goodness of fit tests for the hypotheses of the frequency stirred field distribution in nested chambers are implemented in this paper, and results indicate that the size of the connecting aperture between the nested chambers is a critical factor to the distribution. When the aperture is large enough, the two cavities performs like a single empty reverberation chamber in terms of electromagnetic field and the inner field shows the same result as in the outer chamber. On the contrary, when the size of the aperture is narrowed to small compared to the wavelength, the frequency-stirring field in each cavity seems to be independent of each other and follows a distribution of double-Rayleigh. However, for the transition between these two extreme situations, both hypotheses are found inappropriate. Further studies are underway to quantify the consequences of these results for EMC immunity and shielding measurements.

4. References

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