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RESEARCH ARTICLE

Design of new reverberation chamber for electromagnetic compatibility and wireless device measurement applications and its reproducibility performance validation

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Abstract
This article proposes new reverberation chamber structure for electromagnetic compatibility and wireless device measurement applications. It consists of dual plate type mode stirrers and two types of reflectors that improve its original field uniformity. Based on the SD and eigenmode analysis, their effect is demonstrated, and through the final measured results, it is shown that the proposed reverberation chamber has excellent SD characteristic of <2.5 dB at 650 MHz or higher. In addition, from the viewpoint of its utilization, it is verified that for over the air performance of a commercial long-term evolution mobile phone, its experimental reproducibility is very high, and its results show little difference from those obtained in the anechoic chamber.

KEYWORDS
mode stirrer, reverberation chamber, working volume

1 | INTRODUCTION

The reverberation chamber (RC) recently plays an important role in measuring the performance of wireless and mobile terminals as well as electromagnetic compatibility (EMC) measurements.[1,2] IEC 61000-4-21 specifies the SD within the working volume to be <3 dB to define the field uniformity of an RC. It is clear that the smaller the SD, the more accurate the measurement. To lower the SD, the mode stirring environment in the RC should be improved. As a way to achieve this, it may be proposed to design an efficient mode stirrer or to design a fixed reflectors inside the RC.

This paper proposes the RC structure with new mode stirrers and reflectors to enhance its original field uniformity, and its experimental reproducibility performance is verified. The evaluation of the field uniformity is performed by the SD based on 3D electromagnetic wave simulations.[3] In addition, eigenfrequency shift analysis approach is introduced to gain physical insight into the principles that arise from structural changes in the RC.[4] Based on these approaches, new mode stirrers and two types of reflectors to improve mode stirring environment of the initial RC structure are proposed. Simulated and experimental results show their effects on field uniformity of the RC and good SD performance.

Finally, superior reproducibility performance of the proposed RC is verified by comparing its total radiation power (TRP) and total isotropic sensitivity (TIS) measurement results with the results obtained in a conventional compact anechoic chamber (AC) for a commercial wireless terminal.

2 | RC DESIGN AND ANALYSIS OF EFFECT OF NEW MODE STIRRERS AND REFLECTORS

Figure 1 shows the proposed RC with new mode stirrers and two types of reflectors. Its dimensions are 1400 × 1950 × 1850 mm (length $\boldsymbol{L}$ × width $\boldsymbol{W}$ × height H), and the lowest useable frequency of ideal empty cavity for this size is approximately 338 MHz.[1] However, the start operating frequency of the RC in this article was set to 650 MHz considering measurements at mobile communication frequencies

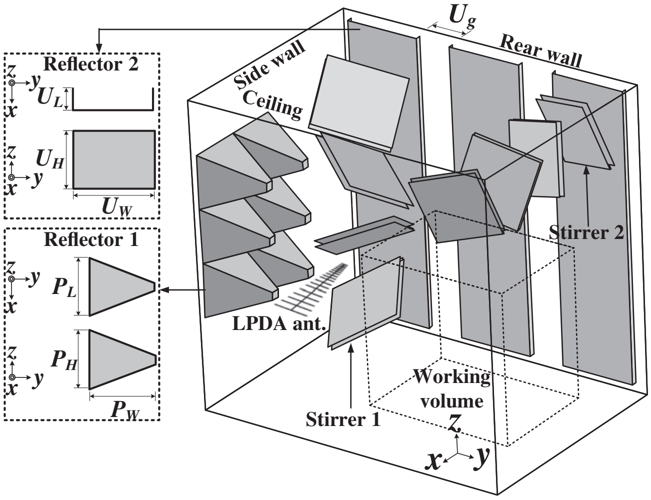

FIGURE 1 The proposed RC structure with dual-type mode stirrers and 2 types of reflectors

and EMC measurements above 1 GHz.[5] The initial basic RC structure consists of only two mode stirrers represented by stirrer 1 and stirrer 2, made up of four square plates with dimensions of widths and heights of 0.46 and 0.4 m, respectively. The working volume to calculate the SD is spaced 0.157 and 12 m from stirrer 1 and from stirrer 2, respectively. These represent distances greater than a quarter wavelength for an operating frequency of 650 MHz. The overall size of the determined working volume are is 0.835 × 0.951 × 0.954 m, and the ratio of working volume to the RC size is approximately 15%.

To investigate the level of the SD of the basic RC structure, a commercial software FEKO, the simulation kernel based on Method of Moment, is used. For the RC walls and the mode stirrers, the zinc and the aluminum plates with the values of $\sigma = 1.67 \times 10^7 S/m$ and $\sigma = 3.816 \times 10^7 S/m$ were used, respectively. The simulations were performed at 25 MHz intervals from 650 MHz to 850 MHz. At this time, a log-periodic dipole array (LPDA) antenna was used as a transmitting antenna, as shown in Figure 1. It was implemented from impedance matching through transmission line network.

The proposed reflectors are shown in Figure 1. Considering the space for the transmitting antenna, the dimensions of the reflector 1 were determined to be 0.324 × 0.36 × 0.324 m. Also, a parametric study according to its number made it possible to determine their final position. Reflector 2 is also shown in Figure 1. For these reflectors, the eigenfrequency shift analysis was performed additionally to investigate the improvement of the field uniformity.[4] It means the amount of shift for the eigenfrequency of the empty cavity resulted from structural changes in the RC. Through the parametric study for the reflector 2, it was confirmed that the smaller the number of the reflector and the larger its width, the larger the eigenfrequency shift. In particular, for three type

TABLE 1 Design parameters related to the reflectors

Parameter	Length (m)	Parameter	Length (m)
Ph	0.324	U_h	1.75
Pl	0.324	U_l	0.03
Pw	0.36	U_w	0.461
		U_g	0.22

2 reflectors, it was found that the condition of $\boldsymbol{U}_w = 0.461$ m and $\boldsymbol{U}_g = 0.22$ m can provide a better environment than the other conditions in terms of mode stirring performance of the RC. The design parameters for the reflectors are listed in Table 1. The new mode stirrers 1 and 2 consisting of dual plates are also shown in Figure 1. The added plates have the same size as the original plates, and they are located at regular intervals denoted by g_{s1} and g_{s2} in the direction perpendicular to the plane from the center of the original ones. Through eigenfrequency shift analysis for these intervals, it was revealed that the smaller the spacing of the plates, the better the eigenfrequency shifts occur. For easy fabrication, g_{s1} and g_{s2} were determined to 0.03 m.

The eigenfrequency shifts for the final design shown in Figure 1 are shown in Figure 2, along with the results for reflector 1 and 2. The clear effect of the new stirrers and the reflectors can be seen after the tenth mode number. Also, it can be confirmed that the RC consisting of reflectors and new stirrers can provide a better mode stirring environment. Figure 3 shows that the level of the overall SD can be lower due to new mode stirrers and reflectors and new stirrers have a positive effect in the band above 725 MHz. Ultimately, it can be said that the two indices show a consistent trend for the field uniformity improvement of the initial structure.

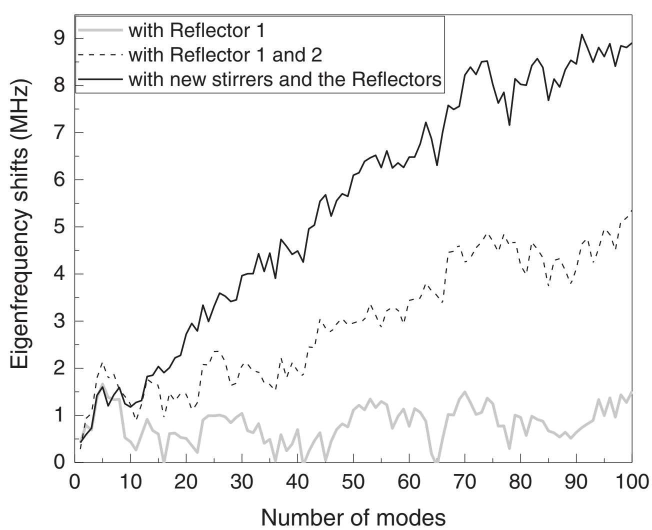

FIGURE 2 Eigenfrequency shifts for the final design compared to those of 2 other conditions

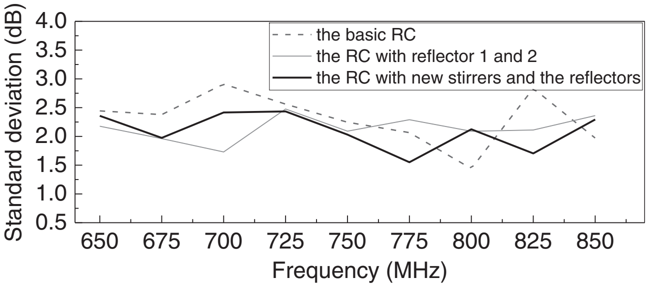

FIGURE 3 Calculated standard deviations (σ_{xyz}) for the RC with and without new mode stirrers and reflectors

3 | RC MEASUREMENTS AND PRACTICAL VERIFICATION

Figure 4 shows photographs of the fabricated RC. Each mode stirrer is rotated by stepper motors controlled by computer software. The LPDA antenna for use as a transmitting antenna operating at 650 MHz or higher was developed independently. All measurements were performed in accordance with the guidelines proposed in Ref. 1. The final measured SD results are shown in Figure 5. At almost all frequencies, the SD was found to be <2.5 dB, and a trend similar to that of Figure 3 was confirmed.

Although the performance of the RC has been verified, its experimental reproducibility performance is an important factor to be finally verified for over the air erformance evaluation of wireless terminals. To check this, TRP and TIS for a commercial long-term evolution (LTE) mobile phone were measured in a small AC and the proposed RC. The AC employs the great circle cut method of CTIA, and all measurements were performed by computer software in accordance with the CTIA guidelines.[6] The overall dimensions of the AC are 3 × 2.5 × 2.5 m ($L \times W \times H$). The TRP and TIS were measured at 897.5 and 942.5 MHz, respectively, which are uplink and downlink frequencies in the LTE band. This TIS is a reference value for determining path loss in an RC. Then, measurements were performed in the proposed RC for the same terminal. Figure 6 shows TRP and TIS results measured in the RC and these are compared with the corresponding values of the AC in Table 2. The reproducibility for TIS in the RC is 0.15 dB, which is better than that in the AC. The TRP results show excellent reproducibility of 0.06 dB. In addition, the difference between the RC and AC results can be said to be mutually reliable up to 0.6 dB. These results demonstrate that the proposed RC is a very attractive auxiliary measurement facility for the performance evaluation of commercial wireless terminals.

FIGURE 4 Photograph of the fabricated RC [Colour figure can be viewed at wileyonlinelibrary.com]

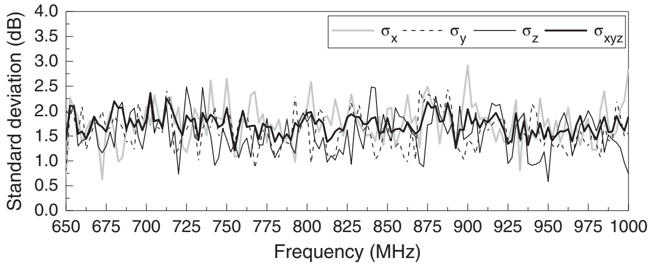

FIGURE 5 The measured standard deviations of the proposed RC

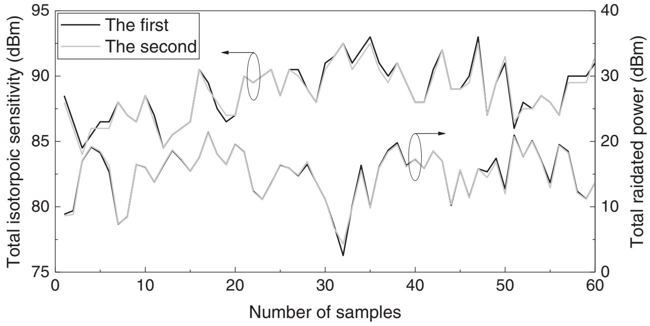

FIGURE 6 TRP and TIS results measured in the RC

TABLE 2 Reproducibility verification results of the RC using commercial mobile phone and comparison with results obtained for an AC

	Number of measurements	AC	RC	$\lvert TIS_{AC}-TIS_{RC}\rvert$ and $\lvert TRP_{AC}-TRP_{RC}\rvert$ (dB)
TIS (dBm)	1	89.42	89.33	0.09
	2	89.68	89.18	0.5
|TIS1-TIS2| (dB)		0.26	0.15	
TRP (dBm)	1	15.77	16.37	0.6
	2	15.78	16.31	0.53
|TRP1-TRP2| (dB)		0.01	0.06	

4 | CONCLUSION

An RC consisting of new reflectors and mode stirrers has been proposed and its performance has been verified. It has an inner size that is approximately the same as or smaller than that of a commercial product and shows good field uniformity performance. Its experimental reproducibility for commercial LTE mobile phone measurements has been found to be very high, and testing showed that there was little deviation from the results measured in an AC.

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