Expanded test frequency band and improved field uniformity in a reverberation chamber for networked system by dual-band quadratic residue diffusers

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Abstract: This paper shows electromagnetic field characteristics in an electromagnetic reverberation chamber that can be used as a test facility for measuring electromagnetic interference and radiated immunity of networked systems. In the reverberation chamber, there is a dual-band diffuser for two different frequency bands and the dual-band diffuser is designed by the combination of different single-band Schroeder-type quadratic residue diffuser (QRD). Finite-difference time-domain (FDTD) numerical analysis method is used to analyse the distribution of electromagnetic fields inside the reverberation chamber. Compared with existing single-band diffuser, this dual-band diffuser in the reverberation chamber not only expands the test frequency band but also improves the performance of the reverberation chamber such as electromagnetic field uniformity, polarisation characteristics, power efficiency and tolerance of the reverberation chamber, which means that the reverberation chamber with this dual-band diffuser is a more efficient test facility than the reverberation chamber with existing units.

Keywords: reverberation chamber; diffuser; field uniformity; frequency band; electromagnetic compatibility; electromagnetic interference.

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1 Introduction

The lowest usable frequency of the electromagnetic reverberation chamber is determined by the number of modes that can ensure the uniformity of the electromagnetic field inside the reverberation chamber of a certain size. And, above this frequency, the uniformity of the electromagnetic field is secured using a stirrer or diffuser in general. The uniform distribution of the electromagnetic field inside the reverberation chamber is determined by the total number of possible modes in the reverberation chamber, the efficiency of the stirrer or diffuser and the Q factor of the medium used to manufacture the reverberation chamber. Currently, many researches on an electromagnetic reverberation chamber using a Schroeder type diffuser are actively underway and this has the advantage of reducing measurement time and maintenance costs compared to a reverberation chamber using a stirrer (Arnaut, 2003; Ayeswarya and Prabha, 2020; Cappetta et al., 1998; Crawford and Koepke, 1986; Davenport et al., 1994; Fiumara et al., 2016; Garimella et al., 2020; Gifuni et al., 2019; Huang, 1999; IEC 61000-4-21, 2011; IEC 61000-4-3, 2020; Kane, 1966; Leo et al., 2020; Mehta and Johnson, 1999; Mendes, 1968; Mur, 1981; Rama and Thangavelu, 2020; Taflove and Brodwin, 1975; Wanderlinder et al., 2017). The reverberation chamber using two stirrers can test networked systems or devices in all frequency bands above the lowest usable frequency of the reverberation chamber. However, the reverberation chamber using a diffuser has a disadvantage that it can secure the uniformity of the electromagnetic field only in the corresponding frequency of the diffuser. By applying the Schroeder method, it is possible to design theoretically a diffuser that operates in all bands above a specific frequency. But, as the physical size of the diffuser increases infinitely as the usable frequency band of the diffuser increases, it is difficult to implement it in reality. Therefore, studies on the expansion of the test and evaluation frequency band of the reverberation chamber using a diffuser are being actively conducted and a dual-band diffuser that can be used in the test and evaluation in wider frequency bands while maintaining the uniformity of the electromagnetic field inside the reverberation chamber is designed and suggested in this paper. The electromagnetic field distribution inside the electromagnetic reverberation chamber with two different single-band diffusers and a dual band diffuser was analysed at frequencies of 2 GHz and 5 GHz by applying the finite-difference time-domain (FDTD) method based on the finite difference method. In order to investigate the distribution and characteristics of the electromagnetic field inside the reverberation chamber to which the above three types of diffuser are applied, the electromagnetic field change state was compared and analysed with the electric field intensity extracted from an appropriately selected test plane and the polarisation characteristics were also investigated.

2 Reverberation chambers

The electromagnetic reverberation chamber must satisfy a multimode electromagnetic environment at the lowest usable frequency for the uniformity of the electromagnetic field. And, for this purpose, a test and evaluation space of an appropriate size must be secured. In this paper, the reverberation chamber of a rectangular structure is adopted as shown in Figures 1 and 2.

Figure 1 Typical reverberation chamber with two stirrers

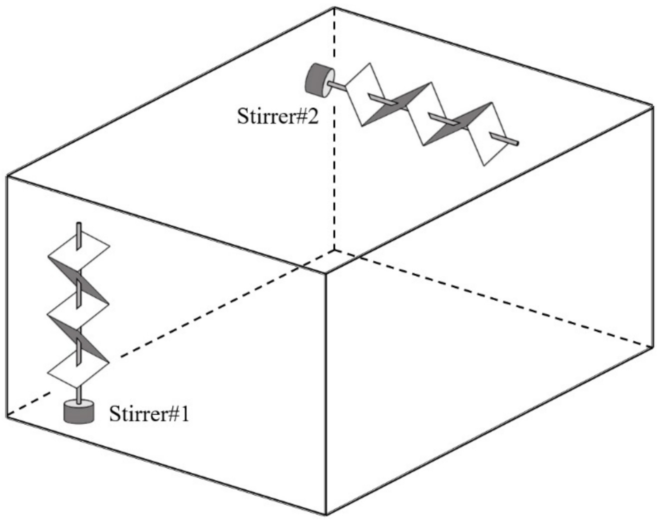
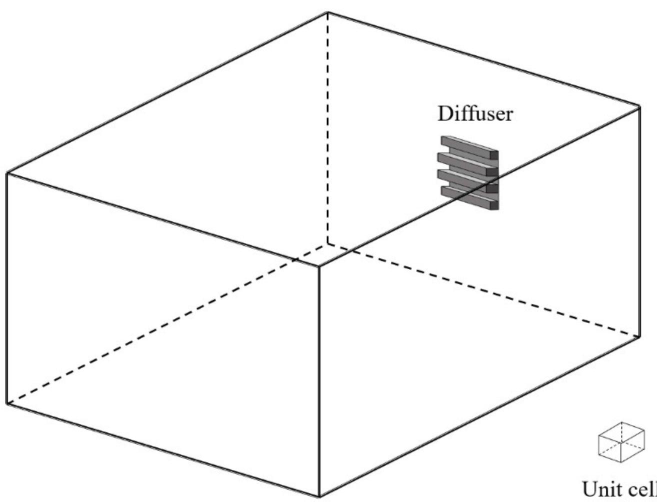


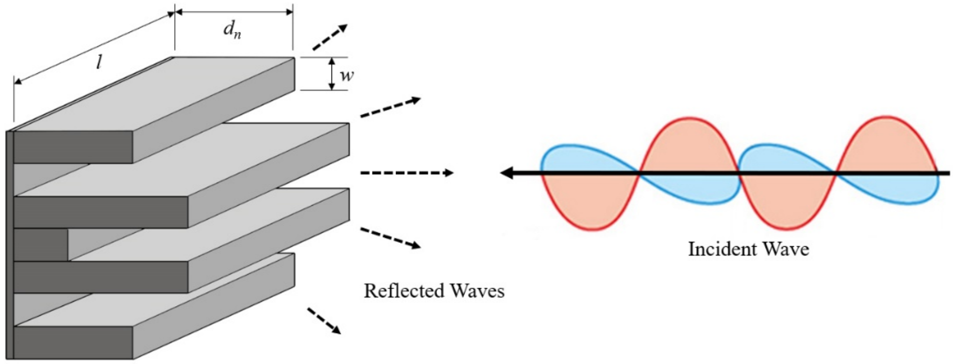
Figure 2 Suggested reverberation chamber with a diffuser



3 Dual-band quadratic residue diffuser

Quadratic residue diffuser (QRD), which was first introduced in the field of acoustics by Schroeder in Germany in 1975, is now applied to electromagnetic reverberation chambers and is used to ensure the uniformity of electromagnetic fields. The basic structure of the diffuser is shown in Figure 3.

Figure 3 Concept of diffuser (see online version for colours)



In this paper, considering the frequency to be analysed, two single-band diffusers which are applied to the frequency ranges of 2 to 3 GHz and 4 to 5 GHz respectively and a dual-band diffuser combined with two single-band diffusers were designed. In Schroeder's 1D QRD, the width of a well (w) is determined by $\lambda_{\max}$ and the depth of well (d_n) is determined by $\lambda_{\min}$ as equations (1) and (2).

$$w = 0.5\lambda_{\max} \tag{1}$$

$$d_n = \frac{S_n \lambda_{\min}}{2N} \tag{2}$$

Figure 4 QRD#1 (for 2–3 GHz) (see online version for colours)

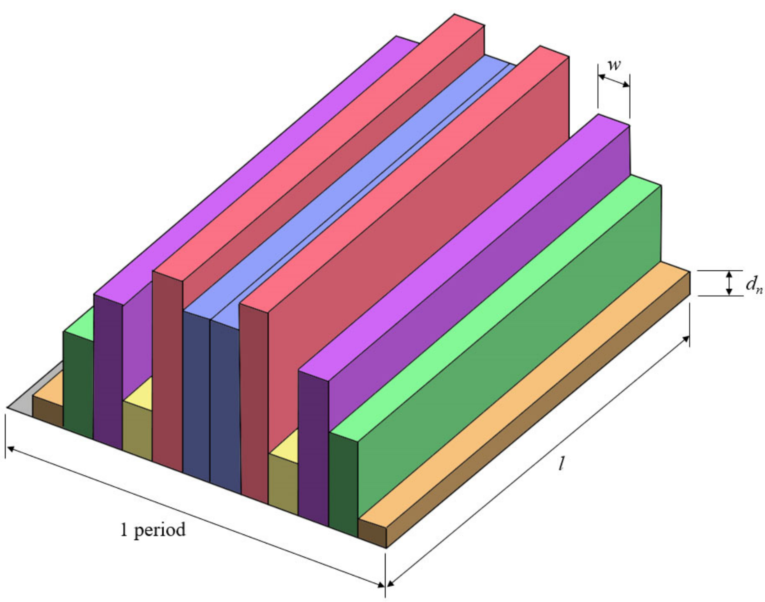


Figure 5 QRD#2 (for 4–5 GHz) (see online version for colours)

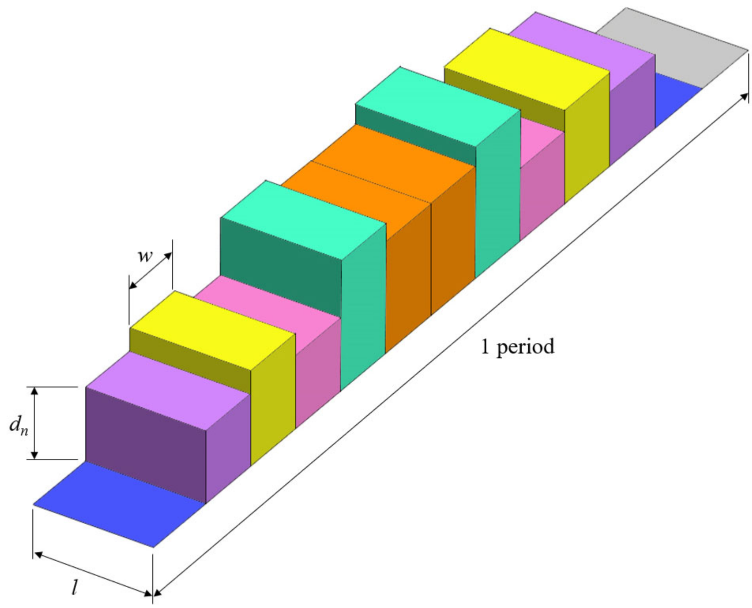
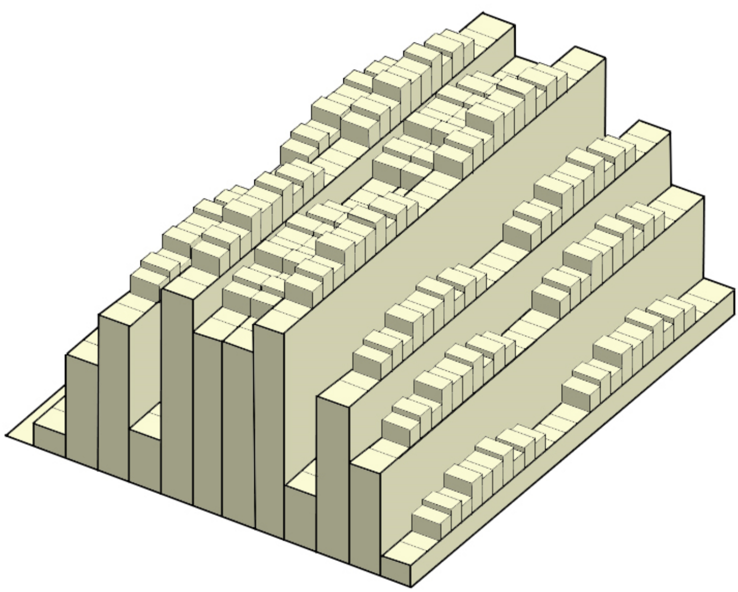


Figure 6 QRD#3 (dual-band)



As the length (l) and period of QRD increase, the efficiency of the reverberation chamber is improved. In this paper, considering the size of the reverberation chamber, two single-band stirrers (QRD#1 and QRD#2) in Figures 4 and 5 are designed to be one period diffuser. The dual-band diffuser in Figure 6 is designed by combining one period QRD#1 and two periods QRD#2. When electromagnetic waves of 2 GHz are scattered, the phase difference of electromagnetic waves is negligible as the reflected waves caused by QRD#2 are not large in phase. This has characteristics similar to the existence of only QRD#1. In addition, when the electromagnetic waves of 4 GHz are scattered, the diffusion can be sufficiently achieved with only QRD#2, but the phase difference due to QRD#1 and the phase difference due to QRD#2 are combined to obtain a better diffusion effect than that of a single-band diffuser.

4 Electromagnetic field analysis

The Schroeder type diffusers designed as Figures 4, 5 and 6 were applied to the electromagnetic reverberation chamber and the FDTD numerical analysis method and XFDTD (2018) simulation tool were used to simulate the electromagnetic field distribution inside the reverberation chamber (XFDTD, 2018). The Yee's algorithm is applied to this analysis and a finite difference equation is used to analyse the electromagnetic field distribution over time and space. The structure of the electromagnetic reverberation chamber was modelled as shown in Figure 2 and the unit cell (Δx, Δy and Δz) was set as 3 mm considering the frequency in order to obtain the electromagnetic field distribution for the frequencies of 2 GHz and 5 GHz.

To satisfy Courant-Friedrick-Lewy (CFL) stability conditions, the discrete time was set to 19.25 ps (= Δt) and the total number of time intervals was set to 20,000. In this paper, the size of the reverberation chamber was set to $260\Delta x \times 270\Delta y \times 260\Delta z$. A source for generating an electromagnetic field was a 1 V sinusoidal point source and it was set in the y-direction at the positions of cells (130, 210, 130). The electromagnetic reverberation chamber, the designed diffuser and the external boundary conditions were all set to perfect electric conductor (PEC).

The diffuser was placed in the center of the x–z plane end inside the reverberation chamber for the three QRDs as shown in Figure 2. In order to investigate the electromagnetic field distribution, the electric field strength was extracted by setting a total of 80 test points, 16 for each plane, from five test planes among the test volumes. All the simulation settings were done in consideration of the definition of anechoic chamber specified in EN61000-4-3 standard.

5 Results

Figures 7 and 8 show the simulated electric field intensity distribution for the x-z plane at y = 151 when the dual-band diffuser is used in the electromagnetic reverberation chamber. Using the numerical analysis results of each diffuser, the results of the mean, standard deviation, maximum, minimum and tolerance for 60 samples, which are 75% of 80 electric field strength values in the test space, are shown in Table 1.

According to Table 1, the single-band diffuser designed in consideration of each frequency band showed good power efficiency and uniformity of the electromagnetic field only at the designed test frequency. On the other hand, in the case of the dual-band diffuser, it can be seen that the power efficiency and the uniformity of the electromagnetic field in both test frequency bands are significantly improved compared to those of the single-band diffuser. In particular, the tolerance of the dual-band diffuser showed excellent electromagnetic field uniformity within 3.0 dB in both frequency bands.

Figure 7 Electric field distribution at 2–3 GHz

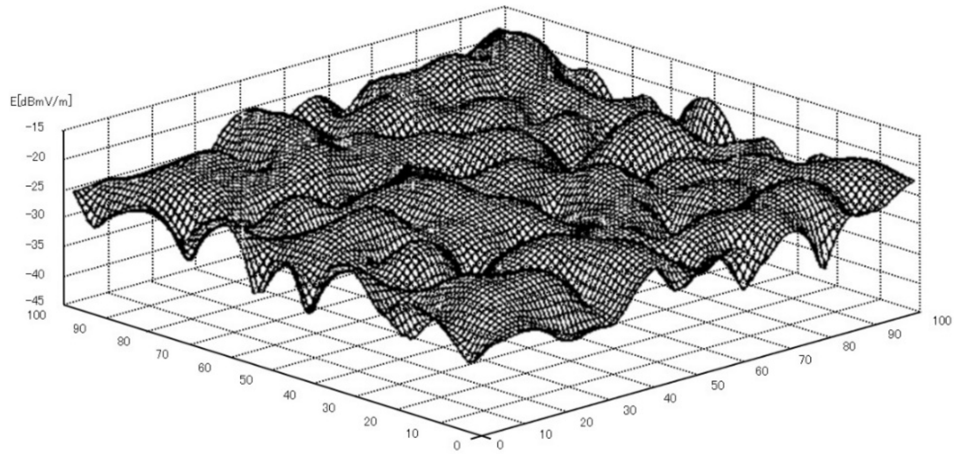
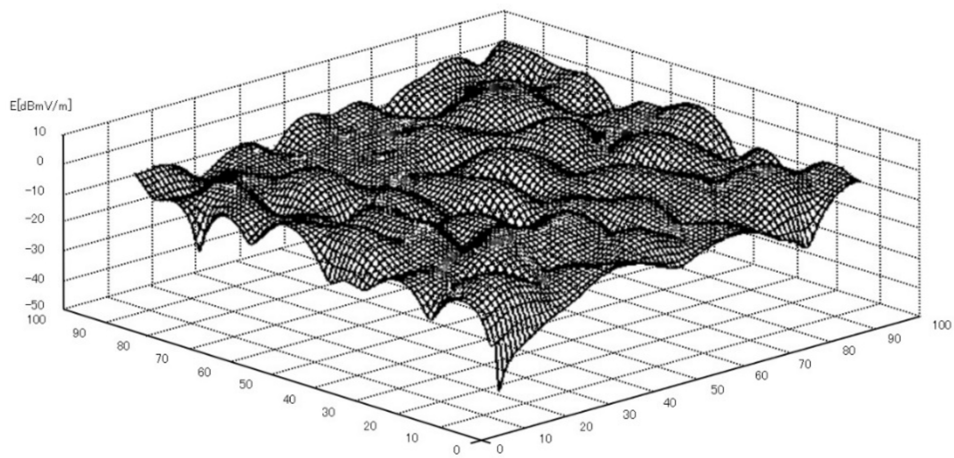


Figure 8 Electric field distribution at 4–5 GHz



To investigate the polarisation characteristics when a diffuser is attached in the reverberation chamber, the values of E_x, E_y and E_z for 34,246 cells of the x-z plane (y = 151 cross-section) are extracted and the cumulative distribution function was found for 75% of samples. The overall distribution followed a chi-square distribution.

Two single-band diffusers (QRD#1 and QRD#2) designed in consideration of each frequency band had good polarisation characteristics only at the corresponding frequency and showed deflection characteristics of a specific polarisation at test frequencies outside the corresponding frequency band. On the other hand, in the case of the dual-band diffuser, it was confirmed that the polarisation characteristics were the best in both test frequency bands and the influence of a specific polarisation was much reduced, especially in the 2 to 3 GHz band. Moreover, E_x, E_y and E_z components are separated and extracted from the total electric field E_t to be analysed by cumulative distribution function.

Table 1 Electric field intensity (75% sampling)

E [dBmV/m]	*QRD#1*		*QRD#2*		*QRD#3*	
	2 GHz	*5 GHz*	*2 GHz*	*5 GHz*	*2 GHz*	*5 GHz*
Mean	37.48	55.68	25.69	58.61	37.02	60.41
Standard deviation	1.49	2.64	3.32	1.48	1.29	1.47
Maximum	38.96	58.32	29.01	60.08	38.31	61.88
Minimum	35.99	53.04	22.36	57.13	35.73	58.94
Tolerance [dB]	2.97	5.28	6.64	2.95	2.58	2.94

6 Conclusions

Compared with Two single-band diffusers capable of scattering electromagnetic waves in the frequency band of 2 to 3 GHz and 4 to 5 GHz, a dual-band diffuser capable of expanding the test frequency band are designed and suggested in this paper. As a result of analysing the electromagnetic field distribution characteristics in each reverberation chamber to which the above three types of diffusers are applied with the FDTD method, the dual-band diffuser is superior to each single-band diffuser in terms of polarisation and electromagnetic field uniformity. It can be seen that the power efficiency is also improved. Particularly, the tolerance for the magnitude of the electromagnetic wave of the dual-band diffuser was found to be within 3.0 dB in both test frequency bands, which means it is confirmed that the electromagnetic field uniformity inside the reverberation chamber was good enough to satisfy the requirements of international standards. As a result of analysing the polarisation characteristics through the cumulative distribution function on the same test plane in the electromagnetic reverberation chamber, the reverberation chamber equipped with a dual-band diffuser had the best polarisation characteristics in both test frequency bands. Especially in the 2 to 3 GHz band, it was confirmed that the influence on specific polarisation was greatly reduced.

To expand the test frequency band, as a substitute test facility for measuring electromagnetic interference and radiation immunity of networked systems, the electromagnetic reverberation chamber using this dual-band diffuser has better power efficiency, uniformity of the electromagnetic field and polarisation characteristics than the reverberation chamber using a single-band diffuser such as QRD#1 and QRD#2. With the results confirmed in this paper, a multi-band diffuser is to be studied in the future.

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