URSI GASS 2023, Sapporo, Japan, 19 – 26 August 2023

On Estimation of Ideal Overmoded Frequency for Metallic Cavity Using the Chaotic Reverberation Chamber

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Abstract

The ideal overmoded frequency is one key indicator for modeling the chaotic field behavior, which determines the conditions under which many theories can be used. To estimate the overmoded frequency, we present a simple maxima-based method using the chaotic reverberant wave field. To replace the traditional mechanical stirrer, frequency stirring technique is used. To verify the proposed method, the measurement is performed in the chaotic reverberation chamber, and the "well-stirred condition" method is used for comparison. The experimental results show that the overmoded frequencies estimated by the proposed method have greater uncertainty, which can be regarded as an alternative procedure if the mechanical stirrer is not available or not convenient to be installed in the cavity.

1 Introduction

Metallic cavities are generally used as electromagnetic interference barriers to protect the sensitive electronics installed inside. For industrial applications, these cavities, e.g., aircraft cabins and below-deck spaces in ships, present irregular structures, and are loaded with various electrical devices. In this case, the electromagnetic field behaviors are mainly described by statistical models [1, 2, 3, 4], but it is worth noting that the frequency of application should also be taken into consideration, where one key indicator is the ideal overmoded frequency (or the frequency corresponding to the "well-stirred condition" [5]).

Recent research on this topic has suggested that the ideal overmoded frequency should be estimated by a sufficient number of independent and identically distributed (i.i.d.) samples, which relies on a goodness-of-fit test according to the ideal distribution, e.g., the field components following a Rayleigh distribution. In fact, the ideal overmoded frequency can be attributed to the inherent characteristics and is closely related to the power loss of the cavity [6]. In other words, the power determines the maximum field, and one may wonder whether the direct analysis of the maximum properties would hold up for the the ideal overmoded frequency.

Moreover, the commonly used methods require the aid of the mode stirred techniques, e.g., the mechanical stirring. For most cavities, however, the mechanical stirrer is not easy to be installed like that of configurations in reverberation chamber (RC) [7].

The aim of this paper is to present a simple method to estimate the ideal overmoded frequency of the metallic cavities using the chaotic reverberant wave field. The coefficient of variation (CV) of the maximum samples is used, taking into account the 3-dB threshold in IEC 61000-4-21, and then in order to replace mechanical stirrers in the metallic cavity, frequency stirring technique is used for the measurement. The experiments are carried out in the chaotic RC, where the "well-stirred condition" method is used for comparison.

2 Method

2.1 CV of the Maxima

Let x and σ be the mean and standard deviation (SD) of the maximum samples $\{x_{n_f}\}$, the CV of the maxima can be defined as

$$cv = \frac{\sigma}{x}. \tag{1}$$

As per IEC 61000-4-21, the threshold of field uniformty is 3-dB, and the threshold for cv can be derived by

$$\sigma_{\mathrm{dB}} = 20\log_{10}\left(\frac{\sigma + x}{x}\right) \leq 3\mathrm{dB} \Rightarrow cv \leq 0.4125. \tag{2}$$

Then, the ideal overmoded frequency should be no less than that where the maximum samples $\{x_{n_f}\}$ are obtained in order to make (2) hold.

2.2 "Well-Stirred Condition" Method

The "well-stirred condition" method is discussed in detail in [5], and herein we show a brief description. For the scattering parameter model shown in Figure 1, we have $|S_{11}| = \sqrt{P_3/P_1}$ and $|S_{21}| = \sqrt{P_2/P_1}$ [8, pp. 32-34]. For the ith position of the mechanical stirrer, S_{11} can be decomposed as [5]

$$S_{11,i} = S_{11}^{fs} + S_{11}^{uns} + S_{11,i}^{sti}, \tag{3}$$

where S_{11}^{fs} is the reflection coefficient measured in the free space, S_{11}^{uns} and S_{11}^{sti} are the unstirred- and stirred-paths in RC respectively. Then, S_{11}^{sti} can be written as [5]

$$S_{11,i}^{sti} = S_{11,i} - \langle S_{11} \rangle, \tag{4}$$

where the symbol $\langle \cdot \rangle$ denotes the overall average value of $\{S_{11,N_s}\}$, and N_s is the number of stirrer positions.

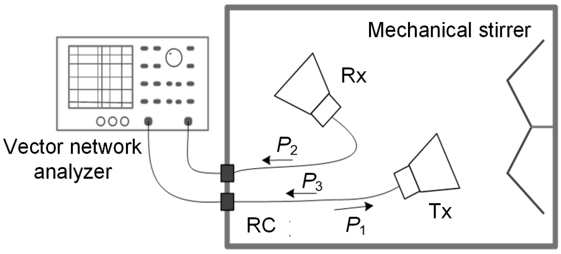

Figure 1. Typical RC configuration with a pair of transmitting (Tx) and receiving (Rx) antennas.

According to the ideal Rayleigh distribution, $\{S_{11,N_s}\}$ are used to perform the Anderson-Darling goodness-of-fit tests for a given frequency, and the modified Anderson-Darling statistic A_m^2 is

$$A_m^2 = A^2 \left(1 + \frac{0.6}{N_s}\right), \tag{5}$$

where A^2 is the Anderson-Darling statistic and

$$A^2 = -\frac{\sum_{i=1}^{N_s} (2i-1) \left[\begin{array}{l} \ln F\left(|S_{11,i}|^2\right) + \\ \ln\left(1 - F\left(|S_{11,N_s+1-i}|^2\right)\right) \end{array} \right]}{N_s} - N_s, \tag{6}$$

and F is the cumulative distribution function of the exponential distribution. The frequency f_1 can be determined if the modified Anderson-Darling statistic $A_m^2 < 1.341$ in terms a desired confidence of 95%.

For $\{S_{11,N_s}\}$, the first-order autocorrelation coefficient is defined by

$$r(\alpha,\beta) = \frac{\mathrm{cov}(\alpha,\beta)}{\mathrm{var}(\alpha)}, \tag{7}$$

where $\alpha = \left(\left|S_{11,i}^{sti}\right|, \left|S_{11,i+1}^{sti}\right|, \ldots, \left|S_{11,N_s-i+1}^{sti}\right|\right)$ and $\beta = \left(\left|S_{11,i+1}^{sti}\right|, \left|S_{11,i+2}^{sti}\right|, \ldots, \left|S_{11,N_s-i+2}^{sti}\right|\right)$. Also for a desired confidence of 95%, the frequency f_2 can be determined if $r(\alpha,\beta) < r_s$, where r_s is the threshold related to N_s (see [9]). As discussed in [5], the ideal overmoded frequency should be the maximum of f_1 and f_2 to ensure that the both thresholds are matched.

3 Measurement

The measurement was carried out in the RC facility with dimensions of 6.16 m × 4.05 m × 3.15 m, and an aluminum cavity sized 0.493 m × 0.389 m × 0.294 m was placed at the working volume of RC, as shown in Figure 2, i.e., the typical nested RC configuration. For the RC facility, the ideal overmoded frequency assessed by the "well-stirred condition" method is about 537.2 MHz (more details about the process can be found in [7, Figs. 3 and 4]), and the oscillating wall stirrer can provide 50 independent stirrer positions (see [10, Fig. 3]). For the aluminum cavity, there is a rectangular aperture with a size of 0.12 m × 0.1 m, which is closed by a metallic plate with a 30-mm-diameter circle aperture; and there is a z-fold stirrer inside the cavity, which is rotating about a vertical axis within a cylindrical volume of 0.26 m height and 0.11 m diameter; the theoretical fundamental resonance is about 500 MHz, and a selfmaded long-wire antenna is used as Rx antenna in the cavity (more details about the cavity and the antenna can be found in [11, 12]).

Regarding the measurement, the vector network analyzer (Rohde & Schwarz ZNB 20) was used, together with a pair of log-periodic antennas for 200 MHz to 1 GHz, and a pair of horn antennas for 1 GHz to 18 GHz. The frequency range investigated was 500 MHz to 6 GHz, where the step frequency was 200 kHz for 500 MHz - 1 GHz, and 1 MHz for 1 - 6 GHz. The oscillating wall stirrer stepped $N_s =$ 50 positions, and for arbitrary oscillating wall stirrer position, the z-fold stirrer stepped n_s =50 positions. Obviously, $N_s \times n_s = 2500$ scattering parameters are recorded.

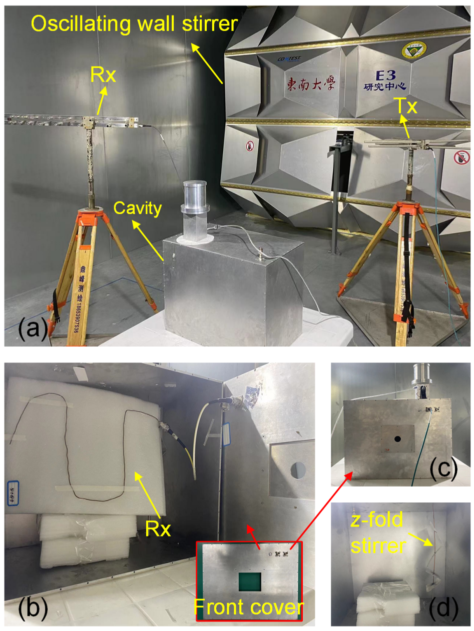

Figure 2. Measurement setup. Interior view of (a) RC configuration and (b) aluminum cavity configuration. (c) Front view of aluminum cavity. (d) Interior view of unloaded aluminum cavity.

4 Results and Discussion

Figure 3 shows the overmoded frequency determined by the "well-stirred condition" method. For the arbitrary oscillating wall stirrer position, S_{11} samples obtained from $n_s = 50$ z-fold stirrer positions are used, where the threshold value is 1.341 for the Anderson-Darling goodness-of-fit test, and 0.28 for the first-order autocorrelation coefficient. In view of this, $N_s = 50$ overmoded frequencies can be estimated by 50 independent tests (performed in the chaotic RC).

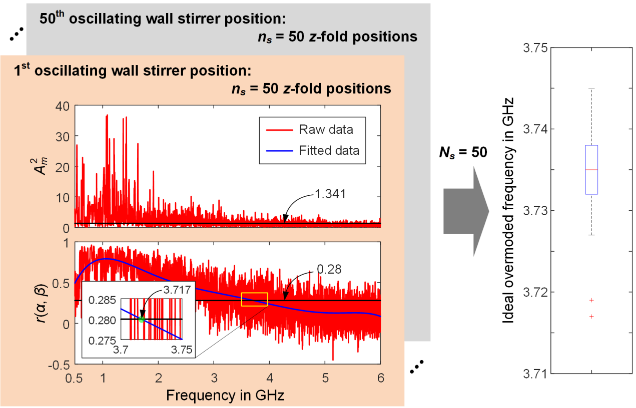

Figure 3. Ideal overmoded frequency determined by the "well-stirred condition" method.

Considering a desired 95% confidence interval (CI), i.e., $x_f - 1.96 * \sigma_f \leq f \leq x_f + 1.96 * \sigma_f$, where x_f and σ_f are the mean and SD of the estimated overmoded frequencies $\{f_1, \ldots, f_N\}$. For $N = N_s = 50$ oscillating wall stirrer positions, the 95% CI is $[3.7247, 3.7439]$ GHz, and the uncertainty is 0.0114-dB by using $20\log_{10}\left(\frac{x_f+\sigma_f}{x_f}\right)$.

Figure 4 shows the overmoded frequency determined by the CV of the maxima. For the arbitrary z-fold stirrer position, S_{21} samples obtained from $N_s = 50$ oscillating wall stirrers are used, where the threshold value is 0.4125. Note that the S_{21} samples are measured between Tx antenna in chaotic RC and long-wire antenna in the cavity (see Figure 2), and the frequency stirring bandwidth is 50 MHz. Thus, $n_f = 50$ maxima can be extracted from $N_s = 50$ samples, where n_f is the number of frequencies for the bandwidth of 50 MHz. For $N = n_f = 50$ frequencies, the 95% CI is $[3.3904, 4.1546]$ GHz, and the uncertainty is 0.4377-dB. Comparatively speaking, the overmoded frequencies determined by the "well-stirred condition" method show lower uncertainty than these estimated by the CV of the maxima, which is contributed by the z-fold stirrer in the cavity. If the mechanical stirrer is not available or not convenient to be installed in the cavity, the overmoded frequency can be approximatly estimated by using the CV of the maxima, and by the chaotic reverberant wave field.

5 Conclusion

In this work, we propose a simple method to estimate the overmoded frequency by using the chaotic reverberant wave field. For this purpose, both the CV of the maxima and the frequency stirring are used, where the theshold value is obtained from the 3-dB limit level in IEC 61000-4-21. The experimental results show that the overmoded frequencies estimated by the proposed method have greater uncertainty. However, this method can be regarded as an alternative procedure if the mechanical stirrer is not available or not convenient to be installed in the cavity.

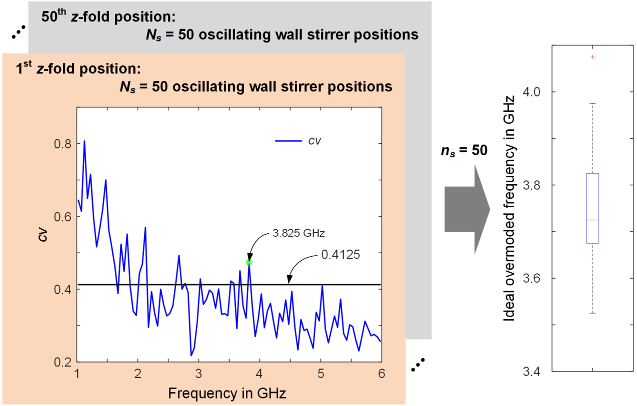

Figure 4. Ideal overmoded frequency determined by the CV of the maxima.

Acknowledgements

This paper is based upon work supported partially by the National Natural Science Foundation of China under Grant 52130706, and supported partially by National Key Laboratory on Electromagnetic Environment Effects and Electro-optical Engineering (NO. 61422062102).

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