The Probability Distribution of the EM Fields in Single-cavity System and the Application of PWB Method

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Abstract—Based on full-wave analysis method, the probability distribution curves of electromagnetic (EM) fields inside a single cavity with and without a mode stirrer are obtained, which obey a kind of unimodal functions. Although this unimodal function does not satisfy the assumption of power balance (PWB) method, the power losses of cavity wall at different frequencies evaluated by PWB method and those calculated by full-wave analysis method are comparable. The change trends of the power losses with frequency almost coincide with each other, and the difference is no more than an order of magnitude. It is remarkable that PWB method costs less than one minute while full-wave analysis method costs more than two hours, and PWB method saves almost 70% memory space. It means that PWB method can indeed give effective data that meet certain accuracy requirement with much smaller computational cost than full-wave analysis method. Finally, for further study of PWB method the inhomogeneous degree is defined to measure the inhomogeneity of EM field distribution inside the cavity.

1. INTRODUCTION

It is difficult to successfully resolve the response, especially, the high frequency response of large complex electronic system to the external EM environment by using traditional EM simulation methods. The main difficulties are the enormous computational cost of the traditional full-wave analysis and the uncertainty caused by the high sensitivity of the high-frequency response [1, 2]. Therefore, it is necessary to introduce some relatively simple estimation methods combined with “statistic language” to analyze the coupling and transmission processes of the external EM energy in electronic system. It has very important theoretical value and application perspective for EM compatibility and EM effects evaluation. The PWB method is a kind of estimation method, used to estimate the magnitude of EM energy in complex system under high-frequency interference. Flexibility and convenience are remarkable features of this method. Its effectiveness has been preliminarily confirmed, but it is still necessary to estimate its use range.

In order to compare full-wave analysis method and PWB method and to validate PWB method, the probability distributions of the EM fields and energy condition in a single-cavity system are attained by these two methods. Moreover, for further study of PWB method, the inhomogeneous degree \( V \) is defined to measure the inhomogeneity of the distribution of the EM fields inside the cavity.

2. PWB METHOD

The PWB method was first proposed by D. A. Hill in 1994, to solve the high-frequency response of a single cavity problem. It was developed as a kind of estimation method by I. Junqua etc., used to estimate the magnitude of EM energy in complex cavity system under high-frequency interference. PWB method is based on statistical concepts. The main assumption is that when the considered system is large enough compared with wavelength of EM interference, EM fields at any point inside the cavity are uniformly distributed random variables of the position. As a result, the mean EM environment can be viewed as pseudo-homogeneous [3, 4], and the cavity that behaves as a pseudo-mode stirred reverberation chamber (MSC) can be approximated.

For such a MSC under steady state condition, the mean power transmitted inside the cavity is equal to the mean power dissipated in different loss mechanisms. For example, for a single-cavity system shown in Fig. 1, it is required that [5],

\[
P_t = P_d = P_{W} + P_{ap} + P_{ant} + P_{obj},
\]

where

\( P_t \) is the mean power transmitted inside the cavity,
$P_d$ is the sum of various dissipated mechanisms inside the cavity,
$P_W$ is the losses in the cavity walls,
$P_{ap}$ is the re-radiation via POEs or generalized apertures,
$P_{ant}$ is the power dissipated in antenna located inside the cavity,
$P_{obj}$ is the absorption of inner objects in the cavity.

3. THE PROBABILITY DISTRIBUTIONS OF THE EM FIELDS IN A SINGLE-CAVITY SYSTEM

In order to verify the assumption of PWB method, the probability distribution that the EM field in a single cavity system obeys is studied. The considered model is constructed as shown in Fig. 2, and there is an ideal metal stirrer rotating different angles freely in the cavity. Based on full-wave analysis method FDTD, 60 situations of the stirrer are sampled, from which the probability distributions of the EM fields inside the cavity can be obtained statistically.

By using curve fitting, we find it satisfies the function: 

$$ y = y_0 + A \cdot e^{-e^{-z}} - z + 1 $$

where $z = (x - x_c)/w$, $y_0$, $x_c$, $w$ and $A$ are all undetermined coefficients. This kind of probability density function is unimodal. The more intense the peak is the better uniformity is. As an example,
Fig. 3(a) shows the statistical results of magnetic field, and Fig. 3(b) shows the curve fitting result at 3.5 GHz.

4. COMPARISON BETWEEN PWB METHOD AND FULL-WAVE ANALYSIS METHOD

To compare the PWB method and full-wave analysis method, the loss power in the cavity walls is considered as an example. For the cavity shown in Fig. 2, the mean power density $S$ inside the cavity is gain by PWB method [5, 6],

$$S = \frac{\lambda}{2\pi V} \cdot \frac{P_{inc}}{Q_1 + \frac{1}{Q_2} + \frac{1}{Q_{wall}}},$$

(2)

where $\lambda$ is the wavelength, $V$ is the volume of the cavity, $P_{inc}$ is the input power, $Q_1$, $Q_2$ and $Q_{wall}$ are the elementary quality factors associated to the aperture 1, the aperture 2 and the cavity walls respectively. The elementary quality factors can be given by the mean coupling cross section $\langle \sigma \rangle$ [4, 5], for instance,

$$Q_{wall} = \frac{2\pi V}{\lambda \langle \sigma_{wall} \rangle}, \langle \sigma_{wall} \rangle = \frac{4S \cdot R_S}{3c \cdot \mu_0} = \frac{4\pi S}{3\lambda} \cdot \sqrt{\frac{\mu_r}{\pi f\mu_0\sigma}},$$

(3)

where $S$ is the cavity surface area, $\mu_r$ is the relative wall permeability, $\sigma$ is the wall conductivity, $R_S$ is the wall surface impedance. Therefore the loss power in the cavity walls $P_{wall}$ can be given by PWB method,

$$P_{wall} = \frac{2\pi V}{\lambda Q_{wall}} \cdot S$$

(4)

Meanwhile, the magnetic field inside the cavity can be obtained by full-wave analysis method, which can be used to calculate the loss power $P_t$ in the cavity walls,

$$P_t = \frac{1}{2} |R_S| \int_S |H_t|^2 ds,$$

(5)

where $H_t$ is the tangential magnetic field component of the cavity inner surface.

The comparison of the loss power in the cavity walls gained by the two methods is shown in Fig. 4. It indicates that the change trends of the two curves with frequency almost coincide with each other, and the difference is no more than an order of magnitude. Moreover, it is remarkable that PWB method costs less than one minute while the full-wave analysis method costs about two hours, and PWB method saves almost 70% memory space. It means that PWB method can indeed give effective data that meet certain accuracy requirement with much smaller computational cost than the full-wave analysis method.
5. INHOMOGENEOUS DEGREE

According to MSC theory, the real and the imaginary parts of electric fields (and magnetic fields) are Gaussian random variables with a mean equal and the same variance. The mean EM environment can be considered as pseudo-isotropic. In engineering practice, the chamber with a stir inside it is modeled as a MSC. To measure the inhomogeneity of the EM fields within the chamber, the inhomogeneous degree $V$ is defined, in terms of the variance $D$ and the mean $E$ of the EM fields,

$$V = \frac{\sqrt{D}}{E}$$  \hspace{1cm} (6)

The calculated results by using (6) show that the relationship of the Inhomogeneous Degree between with and without stir, $V_{2i}$ and $V_{1i}$, always meets (7),

$$V_{1i} \leq V_{2i} \hspace{0.5cm} (i = x, y, z)$$  \hspace{1cm} (7)

which just meet our supposition.

6. CONCLUSIONS

In this paper, the probability distributions of the EM fields in a single-cavity system with or without a stirrer are studied, which obey a kind of unimodal function. Although they are not very satisfied with the assumption of PWB method, the power losses of cavity wall at different frequencies evaluated by PWB and the ones calculated by full-wave analysis are comparable. The comparison of the results shows that PWB method can indeed give effective data that meet certain accuracy requirement with much smaller computational cost than full-wave analysis method. What’s more, the definition of the inhomogeneous degree is the preparation for further research of PWB method. Although only single-cavity system is considered, the above conclusions can be easily extended to the case of multi-cavity system through PWB network formula.

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REFERENCES