Fast Iterative Computation of Internal Field Intensity for Cabin on HIRF Based on Energy Conservation Modification

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Abstract— Aiming at the requirements of internal field strength calculation of electrically large cabin under high intensity radiated field (HIRF), the sub-domain decomposition methods are used for accelerating the calculation of electromagnetic current iteration method. Moreover, multiple reflection field distribution with limited number of reflections are estimated and modified according to the energy conservation principle, as well as with the prior knowledge of reflection field random distribution. Therefore, fast computation of field intensity distribution of electrically large cabin can be realized. The results derived by the proposed method agree reasonably with the results obtained by using the numerical method. Finally, this fast iterative computation method is applied for electric field intensity analysis of oversized cabin with internal stirrer.

1. INTRODUCTION

In modern complicated electromagnetic environment, there are both natural electromagnetic interference sources (such as lightning and static electricity) and human interference sources (such as radar, radio communications, navigation, electronic warfare equipment, and microwave electromagnetic weapons). High intensity radiated fields (HIRF) is one of the major artificial EM interference. Meanwhile, aviation aircraft electronic devices, which have the features of high integrity, accuracy and complexity, are inherently operated in these complicated electromagnetic environments. Studies on HIRF effect are of great significance for the development of civil aircrafts, rockets and satellites.

However, the modeling and simulation for aerospace vehicles on HIRF are very complex. Both the external electromagnetic wave reflection and the internal wave propagation are needed to be considered. Besides, the scale of the calculated structure is usually larger due to the requirements of the largest HIRF effect analysis frequency up to 40 GHz, where the size of passenger cabin of airplane reached to thousands of wavelength. HIRF effect of electrically large structures attract increasing attention in the field of electromagnetic environment.

Time domain methods including FDTD and FIT were used to analyze the electric field distribution for small composite material aircraft below the frequency of 1 GHz [1]. MoM (moment of method) technique was also used for HIRF simulation of aircraft over the frequency range of 10 kHz $\sim$ 1 GHz [2]. In the European HIRF SE projects, many numerical method including MoM and multilevel domain differentiated (MDD) are utilized for HIRF simulation within the low frequency range [3]. While in the frequency range above 3 GHz, a called power balance method (PWB) was proposed for the solution of HIRF effects, but it only gives the mean power densities in the aircraft cabin [4].

In this paper, the sub-domain decomposition technique is investigated based on the electromagnetic current iteration method. The contribution of multiple reflections for field distribution can be rapidly pre-estimated according to the energy conservation principle, as well as the prior knowledge of random degree of multiple reflection fields. An aircraft cabin is utilized to validate the proposed method. Reasonable agreement is obtained by comparing the results from proposed method with those from numerical method. Moreover, the presented method is used for the analysis of field distribution for oversized cabin with internal stirrer.

2. FAST ITERATIVE CALCULATION METHOD FOR FIELD DISTRIBUTION OF CABIN

The solution of cabin structure is called "internal problem". The electromagnetic wave bounced back and forth multiple times in the cabin. The iterative calculation for total reflection is usually time-consuming. Moreover, the convergence of computation is poor. While the high order reflection of electromagnetic wave becomes isotropic after sufficient reflections, and it can be estimated efficiently by using the PWB method. In this paper, based on the electromagnetic current iteration method in [5], the fast calculation of electric field distribution for electrically large cabin structure is realized according to sub-domain decomposition and modification of energy conservation principle.

2.1. Sub-domain Decomposition Iteration Method

The cabin can be divided into many sub-regions according to geometric shape of the structures. The connections between adjacent sub-regions are treated with virtual surfaces. For the sake of realizing iteration acceleration, the ratio of area for virtual surface to area for cabin wall is required to be less than 0.5.

The electromagnetic current iterative method mainly based on Huygens principle, which gets the induced currents with the equivalent electromagnetic current on the connection faces, S_a. If we consider a metal cabin, the mth reflection magnetic field can be expressed as

$$\mathbf{H}_c^{(m)}(r_c) \approx \int_{S_a} \mathbf{J}_a^{(m)}(r_a) \times \nabla' g(r_c - r_a) dS_a + \frac{1}{\mathrm{j}kZ_0} \nabla \times \int_{S_a} \mathbf{M}_a^{(m)}(r_a) \times \nabla' g(r_c - r_a) dS_a, \quad (1)$$

where $\mathbf{J}_a^{(m)}(r_a) = \hat{n} \times \mathbf{H}_a^{(m)}(r_a)$, $\mathbf{M}_a^{(m)}(r_a) = E_a^{(m)}(r_a) \times \hat{n}$ are the equivalent electromagnetic current densities, respectively. $\hat{n}$ is the normal of connection face. $\vec{E}_a^{(m)}(r_a)$ and $\vec{H}_a^{(m)}(r_a)$ are the electric and magnetic fields at the location of r_a on the connection face of S_a, respectively. $\vec{H}_a^{(m)}(r_a)$ is approximated by

$$\mathbf{H}_a^{(m)}(r_a) \approx \int_{S_c} \mathbf{J}_c^{(m-1)}(r_c) \times \nabla' g(r_a - r_c) dS_c, \quad (2)$$

where $\mathbf{J}_c^{(m-1)}(r_c)$ is the induced current of cabin. The initial inwall induced current can be calculated with physical optics (PO).

$$\vec{J}_c^{(0)}(r_c) = 2\hat{n} \times \vec{H}_c^{(0)}(r_c) \quad (3)$$

When the whole cabin is divided into several sub-domains, a single iteration calculation contains positive and negative iterative processes. The positive process is to use equations from (1) to (3) for calculating the electromagnetic transmission and reflection in each sub-domain, while the negative process is to use equations from (3) to (1) inversely.

2.2. Modification with Energy Conservation

Observing iterative process of electromagnetic wave propagation and reflection, field intensity distribution in the cabin can be considered as the superposition of different reflection fields.

$$\mathbf{E}(r) = \mathbf{E}_f^{(m-1)}(r) + \mathbf{E}^{(m)}(r) + \mathbf{E}_z^{(m+1)}(r) \quad (4a)$$

$$\mathbf{E}_f^{(m-1)}(r) = \sum_{n=0}^{m-1} \mathbf{E}^{(n)}(r) \quad (4b)$$

$$\mathbf{E}_z^{(m+1)}(r) = \sum_{n=m+1}^{\infty} \mathbf{E}^{(n)}(r) \quad (4c)$$

where, $\mathbf{E}_f^{(m-1)}(r)$ is the sum of electric fields including the incident field, as well as first reflection field, second reflection field, and till to the $(m-1)$th reflection field. $\mathbf{E}^{(m)}(r)$ is the sum of electric field of the mth reflection and beyond. According to the energy conservation principle, EM powers which go into the cabin window, runoff the cabin window, and dissipate in the wall are balanced. The powers go into and runoff the window can be expressed by

$$P^{(mn)} = \int \mathbf{E}^{(m)} \times \mathbf{H}^{(n)} \cdot \mathrm{d}s \quad (4d)$$

The relations of energy balance can be obtained when lossless cabin walls are considered.

$$P_{in} = P_{out}^{(0\sim m)} + P_{out}^{(z)} + P_{out}^{(mz)}$$

where P_{in} is the power from which the incident field goes into the cabin. $P_{out}^{(0\sim m)}$ is the sum of powers including the incident field, as well as first reflection field, second reflection field, and till to the mth reflection field. $P_{out}^{(z)}$ is overall power of the mth reflection and beyond. $P_{out}^{(mz)}$ is the coupling energy of $P_{out}^{(0\sim m)}$ and $P_{out}^{(z)}$, which is small due to the strong randomness of high order reflection field. The spurious wave electric field can be approximated by:

$$E_z^{(m+1)} \approx a\sqrt{\frac{P_{in}-P_{out}^{(0\sim m)}}{P^{(m)}}}E^{(m)} \tag{4e}$$

where, E_z is the magnitude of spurious wave. P_{in} is the incident power. $P^{(m)}$ is the power of mth reflection. $E^{(m)}$ is the magnitude of mth reflection wave. a is a correction factor which depends on the coupling energy between spurious wave and low-order reflection wave.

3. SIMULATION OF HIRF EFFECT FOR TYPICAL CABIN

3.1. Results Comparison

A rectangular box is used for ensuring the validation of the proposed method, as shown in Fig. 1. The dimensions are 2 m × 0.5 m × 0.5 m. The frequency is 10 GHz. Five orders reflection are taken into account with the iterative calculation method and the correction factor of 0.5 in (7) is selected. The obtained electric field results in an appointed plane are compared with the results by MoM. Table 1 lists all the mean electric fields, which shows good agreements.

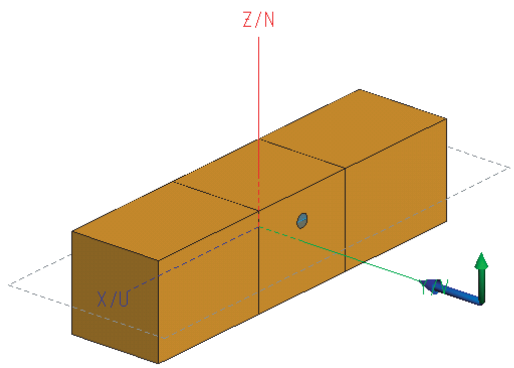


Figure 1: Simplified cabin model for validation.

Table 1: The comparison of electric field results.

The radius of aperture (mm)	Mean electric field inside the cabin (V/m)	
	Proposed method	MoM
15	0.12	0.12
25	0.21	0.18
35	0.23	0.22
45	0.28	0.28

3.2. Application for Cabin with Stirrer

Stirrers are often used inside the cabin to simulate the different electromagnetic wave propagation direction of incidence, especially for the high frequency cases. The stirrer could improve the efficiency of HIRF effects testing. In this paper, the proposed method is applied to EM computation for aircraft cabin with a length of 18 m. The cabin is decomposed to nine sub-domains with each length of 2 m, as shown in Fig. 2. The frequency of 10 GHz is considered again and 22 cores are configured for parallel computation. It only takes 10 minutes for electric field analysis on the whole solving process.

Figure 3 shows the electric field distribution inside the cabin. The results are given when azimuth angle are 30°, 40°, and 50° for stirrer. It can be seen that the beam of reflection wave changes with different azimuth angles and sweeps through the left side of cabin which is the area of smaller field intensity. These results also conform to the law of electromagnetic wave reflection.

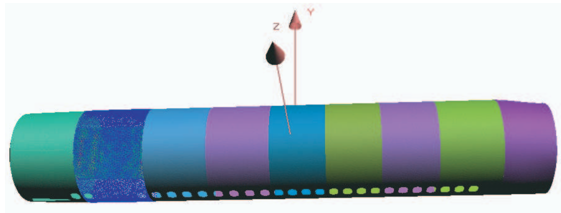
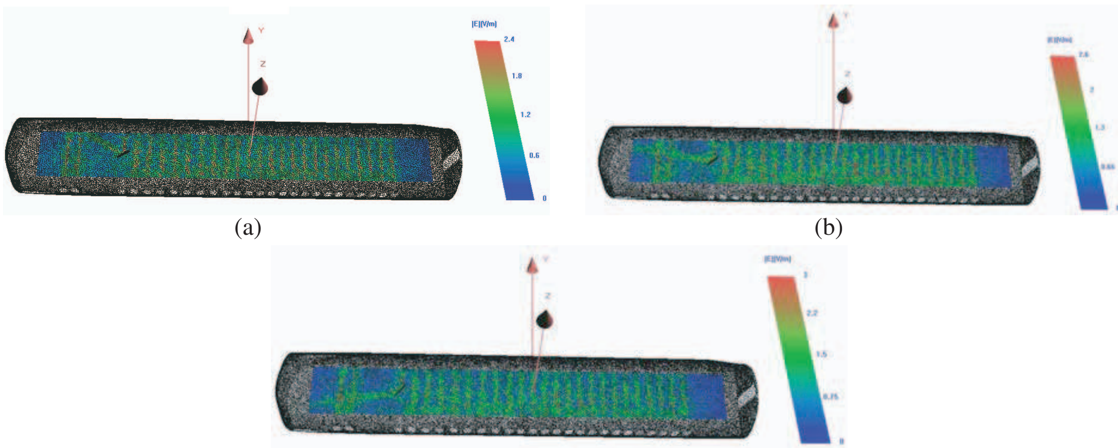


Figure 2: The decomposition of a typical cabin.



(a) (b) (c)

Figure 3: The electric field distribution of cabin with an internal stirrer. (a) Azimuth angle of 30°. (b) Azimuth angle of 40°. (c) Azimuth angle of 50°.

4. CONCLUSION

The sub-domain decomposition technique is investigated based on the electromagnetic current iteration method. The electric field distribution of cabin is approximated according to the energy conservation principle and could be rapidly pre-estimated. The proposed method is used for the analysis of field distribution for oversized cabin with internal stirrer and reasonable results are obtained.

ACKNOWLEDGMENT

This work was supported in part by the National Science Foundation of China (No. 61302036).

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