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An Equivalent Scaling Measurement Method for Lossy Electromagnetic Target Based on Surface Impedance

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Abstract. In this paper, a revised method based on surface impedance for scaling measurement of lossy electromagnetic target (SurImScalingM) was constructed to solve such prominent problems as high difficulty of organization, time consuming and high cost of the test for full-size target electromagnetic signature. First, impedance boundary conditions were used to approximate the boundary conditions under specific conditions, and the relationship between the tangential electric field outside the boundary, magnetic field and boundary surface impedance was established by "surface impedance"; then, geometrical factors were introduced to characterize the relationship between RCSs of the model applying different lossy dielectric materials at the same frequency; finally, the RCS of the original model was obtained by perfect scaling conditions based on the geometric factors obtained by measurement. In this paper, the verification test of the construction method was carried out based on the simulation data. The results showed that the RCS of the corner reflector with six kinds of lossy electromagnetic materials had an error of 0.688-0.815dB, which could meet the requirements for equivalent scaling measurement of full-size target.

Keywords. Surface impedance, lossy electromagnetic target, equivalent scaling measurement.

1. Introduction

With such characteristics as small size of experimental model, low processing cost, low difficulty in testing and low cost, scaling model measurement has become an effective and low-cost approach in the research of measurement of electromagnetic signature [1-3]. On the premise of satisfying the perfect scaling conditions, the technology has been extensively used. The electromagnetic similarity theory and scaling relationship of the perfect conductor target are well-known, and have been widely used in the scaling measurement of various large metal target electromagnetic scattering characteristics [4-5]. However, problems in the scaling equivalent measurement of target with electromagnetic lossy materials have not been effectively solved. Many foreign scholars

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have made appropriate improvements to Sinclair's classical electromagnetic similarity theory to expand its range of application to some extent. They, from the perspective of Maxwell equation, introduce the reasons why the classical electromagnetic theory is only applied to metal materials or perfect dielectric (low-loss dielectric approximately meets the condition), analyze several possible scaling measurement schemes, and finally give three similarity rates of lossy target scaling measurement [6-8]. However, due to the limitation of the application conditions of the "Leontovic impedance boundary condition" itself, this theory is more applicable to the specular scattering source. In relevant experiments conducted abroad, the result that it was close to the range of vertical incidence (specular reflection)±20° was given [9-10]. Other types of scattering sources, such as strong coupling, edge or cuspidal diffraction and surface wave, were not specified. In the field of scaling model measurement, a number of research institutions at home and abroad have special labs for electromagnetic scaling measurement, and have carried out plenty of work in this direction. However, there are few articles on the scaling measurement of RCS of lossy target scattering sources [11-12]. The domestic system has developed the design and test methods for the scaling models of low-loss dielectric materials such as metal, but there are few studies on the equivalent scaling and testing of high-loss dielectric materials. According to the searched literature, domestic scholars, by introducing the concept of "equivalent surface impedance" into the study on the scaling measurement law of lossy targets [13-14] and using the "Leontovich impedance boundary condition", put forth the concept of "lossy scatterer scaling factor", which explained the physical significance of the whole process in a deeper and clearer way; they also conducted relevant experiments, and the results supported the theory the author proposed [15-16]. In this paper, a revised method based on surface impedance for scaling measurement of lossy electromagnetic target was constructed to solve such prominent problems as high difficulty of organization, long cycle and high cost of the test of full-size target electromagnetic signature. Through the simulation and test verification, the errors of the proposed methods were all lower than 1.6dB, suggesting that they could effectively solve the problems of scaling measurement and equivalent characteristic mapping of large-size targets.

2. Proposed Algorithm

The boundary conditions of the target impedance are shown in Equation (1).

$$\vec{E} - \vec{n}(\vec{E} \cdot \vec{n}) = \eta_s \vec{n} \times \vec{H} \tag{1}$$

Where, $\vec{E}$ is the electric field, $\vec{n}$ is the outer normal vector, η_s is the surface impedance, and H is the magnetic field.

The restricted conditions of the refractive index of the impedance boundary conditions are shown in Equation (2).

$$\begin{cases} \mathrm{Im}(n) \geq \dfrac{2.3}{k_0 \rho} \\ |n| \sim 6 \end{cases} \tag{2}$$

Where, the wave number *n* is the complex refractive index of lossy dielectric, Im(*n*) is the imaginary part of *n*, k_0 is the electromagnetic field on the free space size of the boundary, and ρ is the minimum radius of curvature of the boundary.

The surface impedance is defined as Equation (3).

$$Z_s = \begin{cases} j\frac{\omega\mu}{k_t \cos(\theta_t)} \tan(k_t \cos(\theta_t) \cdot d) \\ j\frac{k_t \cos(\theta_t)}{\omega\varepsilon} \tan(k_t \cos(\theta_t) \cdot d) \end{cases} \tag{3}$$

The normalized surface impedance is defined as Equation (4).

$$\eta_s = \frac{Z_s}{Z_0} \tag{4}$$

The RCS of lossy target is expressed as Equation (5).

$$\sigma = \sigma_0 |\Gamma|^N = \sigma_0 \left| \frac{\eta_s - 1}{\eta_s + 1} \right|^N \tag{5}$$

$$N = \frac{\ln(\frac{\sigma_C}{\sigma_0})}{\ln(\frac{\eta_s - 1}{\eta_s + 1})} \tag{6}$$

Where, σ is the RCS of lossy electromagnetic target, σ_0 is the RCS of metal target, σ_c is the RCS of the target applying lossy electromagnetic materials, and *N* is the geometrical factor.

3. Experiments and Results

In this paper, the Angular reflector RCS simulation data with electromagnetic-consuming materials is used to verify the method constructed by this paper, the full size of the Angular reflector is 56cm, the scale model is 3.5cm, and the 6 kinds of consumable electromagnetic materials used are tuft net, camouflage net, honeycomb board, foam board, coating, and glass. For more information, seen in table 1, table 2, and table 3.

Table1. Angular reflector size and band information for simulation test

Scale	**Dimensions (side length)/m**	**Simulation band/GHz**	**Simulation band spacing**
1:1	0.56	5.5-6.0	0.01GHz
1:16	0.035	88-96	0.16GHz

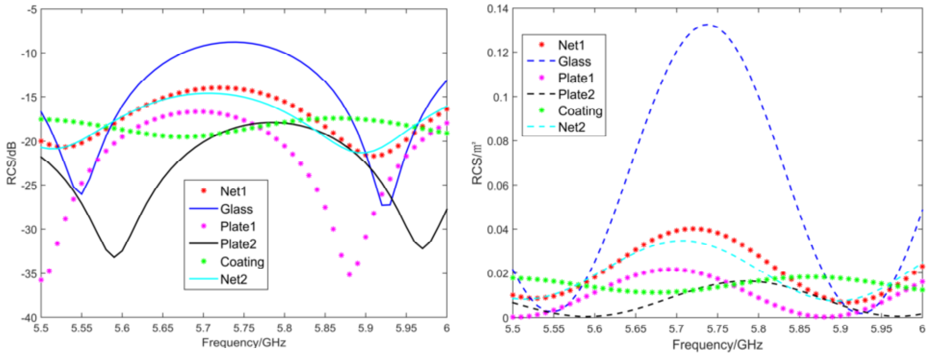
Table2. Average electromagnetic parameters of 5.5-6.0 GHz for consumable electromagnetic materials

	The real part of the dielectric constant	**Dielectric constant imaginary part**	**Permeability real part**	**Imaginary permeability**
Net 1	2.981	1.794	1	0
Net 2	10.472	1.398	1	0
Plate 1	2.981	1.794	1	0
Plate 2	2.881	0.469	1	0
Coating	20.349	1.281	2.907	2.548
glass	4.909	0.641	1	0

Table3. Average electromagnetic parameters of 88-96GHz for consumable electromagnetic materials

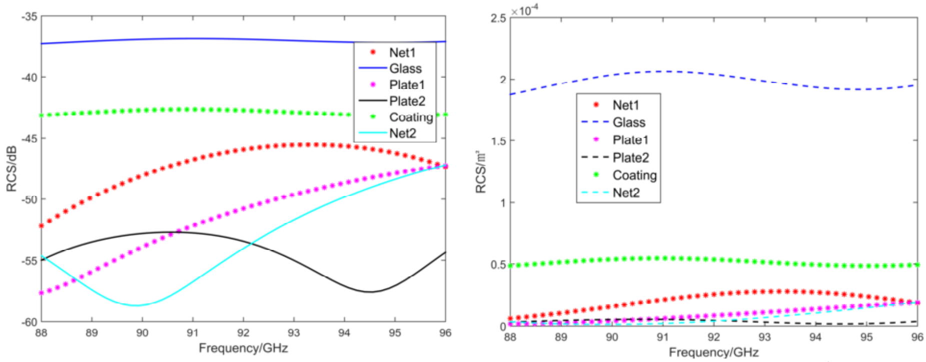
	The real part of the dielectric constant	Dielectric constant imaginary part	Permeability real part	Imaginary permeability
Net 1	3.4	0.34	1	0
Net 2	3.4	0.34	1	0
Plate 1	2.4	0.96	1	0
Plate 2	1.5	0.15	1	0
Coating	6	0.6	0.95	0.067
glass	4.5	0.45	1	0

The simulation results of the 1:1 prototype Angular reflector and 1:16 shrinkage Angular reflector model after applying 6 dielectric materials are shown in figure 1 and figure 2.



(a) RCS simulation results/dB (b) RCS simulation results/m²

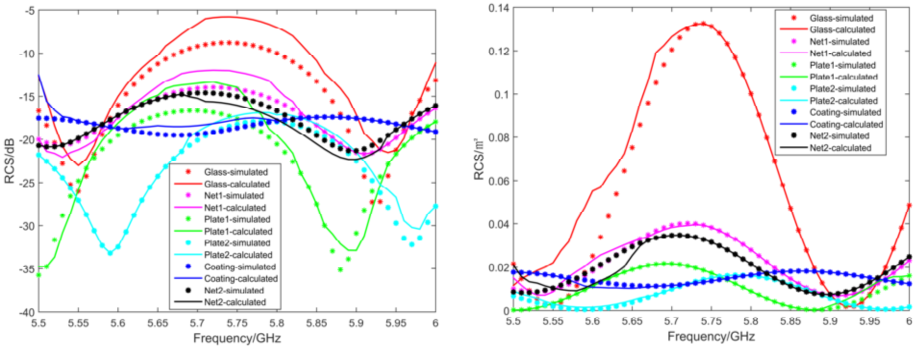
Figure 1. 2 RCS in the 5.5-6 GHz band for six electromagnetic-consuming materials



(a) RCS simulation results/dB (b) RCS simulation results/m²

Figure 2. RCS in the 88-96GHz band for six electromagnetic consumable materials

4 RCS in the 5.5-6 GHz band for six electromagnetic consumable materials is shown in figure 3, the error between the simulation results and the results derived by the method constructed in this paper are shown in table 4.



(a) RCS calculation and simulation results/dB (b) RCS calculation and simulation results / m²

Figure 3. RCS for six electromagnetic consumable materials

Table4. Simulation results and results derived by SurImScalingM

lossy electromagnetic materials used for target	average error /db
Net 1	0.688
planet 1	0.735
planet 2	0.808
Coating	0.789
Net 2	0.721
glass	0.815

4. Conclusion

In order to solve the time consuming, high difficulty and other engineering problems of testing for the full-size target electromagnetic scattering characteristics, this paper constructed a scaling target equivalent measurement and deduction method based on target impedance boundary conditions, and conducted the simulation verification test of the RCS of angular reflector with six kinds of lossy electromagnetic materials, thus obtaining the following conclusions.

(1) Angular reflector with six kinds of lossy electromagnetic materials, net1, net 2, planet 1, planet 2, coating, glass, average calculation errors are 0.688,0.721,0.735,0.808,0.789, 0.815 respectively.

(2) The error of the equivalent scaling measurement method constructed in this paper is less than 30%, which can meet the requirements of equivalent scaling measurement for full-size targets.

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