3D Electromagnetic Inverse Scattering by Magneto-Dielectric Objects with Arbitrary Anisotropy in Layered Uniaxial Media

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***Abstract*—In this paper, electromagnetic (EM) inverse scattering of magneto-dielectric objects with arbitrary anisotropy embedded in layered uniaxial media are studied. Variational Born iterative method (VBIM) combined with stabilized biconjugate gradient fast Fourier transform (BCGS-FFT) is employed to reconstruct the 18 anisotropic dielectric parameters simultaneously. The VBIM is further enhanced by the structure consistency constraint (SCC) to improve the reconstructed arbitrary anisotropic permittivity, permeability as well as conductivity. We reconstruct the multiple anisotropic parameters of a concave object embedded in layered uniaxial media to show the feasibility of the proposed inverse algorithm.**

I. INTRODUCTION

In the past three decades, electromagnetic (EM) inverse scattering have been intensively studied due to their wide applications in microwave imaging [1], geophysical remote sensing [2], circuit design, etc. In sophisticated numerical models, the layered structures and anisotropy of the media [3] are considered. Therefore, it is important to study the electromagnetic inverse scattering of arbitrary anisotropic objects embedded in layered media.

In the forward EM scattering modeling, the fast solver, stabilized biconjugate gradient fast Fourier transform (BCGS-FFT) uses the hexahedron mesh in the discretization of volume integral equation (VIE) and facilitates the direct application of FFT acceleration. In addition, BCGS-FFT can be easily combined with inverse algorithms to reconstruct the unknown scatterers which also will be carried out in this paper. Therefore, BCGS-FFT is adopted in our forward model. In the inverse modeling, we adopt the Variational Born iterative method (VBIM) which converges faster than Born iterative method (BIM) and consumes less memory than distorted Born iterative method (DBIM). It has been combined with structure consistency constraint (SCC) to invert for the biaxial anisotropic scatterers in our previous work [4].

In this paper, we use the BCGS-FFT-VBIM to reconstruct the mutiple dielectric parameters of magneto-dielectric objects with arbitrary anisotropy embedded in layered uniaxial media. Eighteen anisotropic parameters including the permittivity, permeability as well as conductivity for arbitrary anisotropic scatterers are retrieved simultaneously. The organization of this paper is as follows. In Section II, we briefly describe the mathematical formulation of the anisotropic inverse scattering. In Section III, a typical numerical case is demonstrated. Finally, in the last section, conclusions are draw.

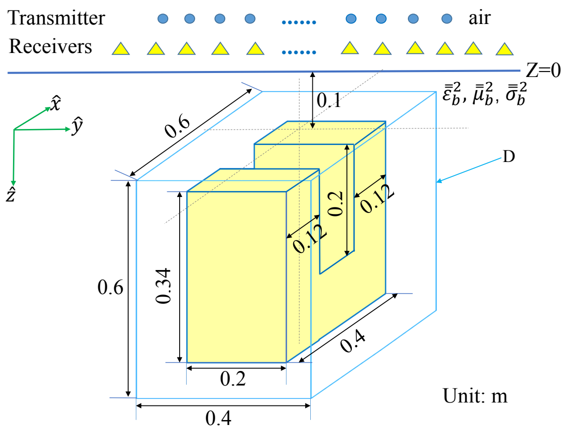

Fig. 1. The configuration of the inversion model with a concave scatterer with the dimension of 0.4 m × 0.2 m × 0.34 m.

II. FORMULATION

In the VBIM algorithm, the cost function is defined as

$$F\left(\delta\mathbf{y}_{n+1}\right)=\frac{\parallel\delta\mathbf{L}_n-\mathbf{B}_n\delta\mathbf{y}_{n+1}\parallel^2}{\parallel\delta\mathbf{L}_n\parallel^2}+\gamma^2\frac{\parallel\delta\mathbf{L}_n\parallel^2}{\parallel\delta\mathbf{y}_n\parallel^2}\qquad(1)$$

where $\mathbf{L}_n$ is the scattered field data in the $n$the iteration, $\mathbf{B}_n$ is a matrix which is composed of the Green's functions in layered media and the total fields obtained by the forward solver BCGS-FFT, $\mathbf{y}_n$ is the contrast function, γ is the regularization factor, and $\|\cdot\|$ is the L2 norm. The minimization of the this cost function can be solved by using the conjugate gradient (CG) method [5].

TABLE I
THE SCATTERER DIELECTRIC PARAMETERS OF THE CONCAVE OBJECT

Parameter / scatterer	ε_{11}	ε_{12}	ε_{13}	ε_{22}	ε_{23}	ε_{33}	μ_{11}	μ_{12}	μ_{13}	μ_{22}	μ_{23}	μ_{33}	σ_{11}	σ_{12}	σ_{13}	σ_{22}	σ_{23}	σ_{33}
concave object	2.4	0.6	0.4	2.0	0.5	2.8	1.7	0.5	0.4	1.6	0.5	2.5	5	4	3	6	4	7

Remark: the unit of σ is mS/m.

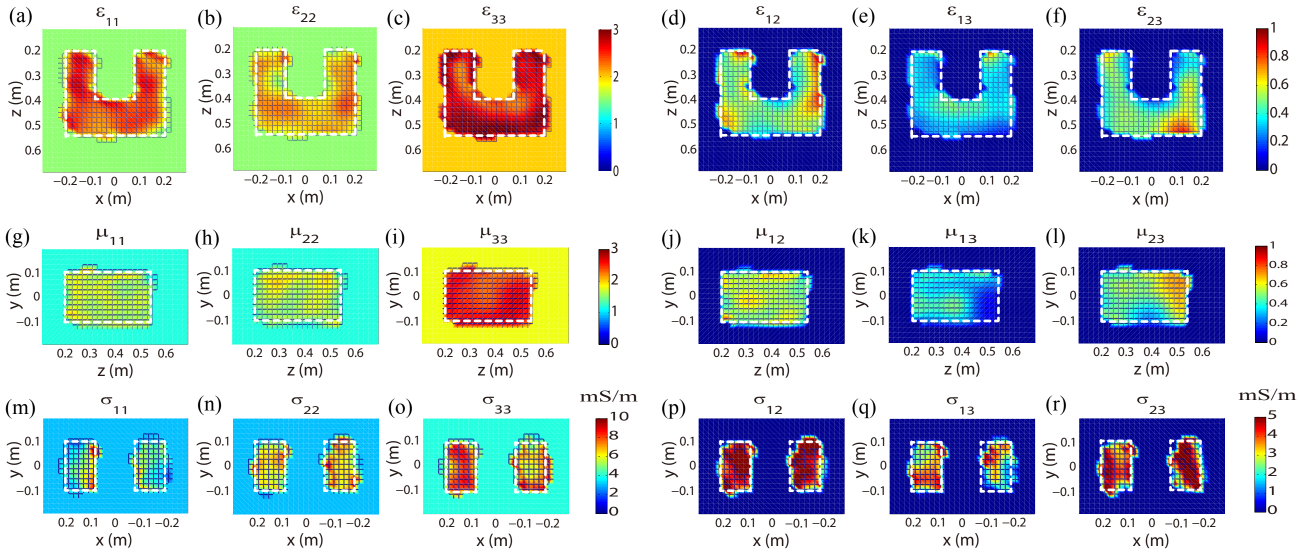

Fig. 2. The detailed 2D slices of reconstructed results for the concave object by VBIM-SCC. Different parameters are depicted by different slices.

III. INVERSION ASSESSMENT

In this section, we perform the inversion to reconstruct a concave object with arbitrary anisotropy embedded in layered uniaxial media. There are totally two layers. The top layer is air and the bottom layer has the uniaxial dielectric parameters. They are

$$\overline{\overline{\varepsilon}}_b^2 = diag\{1.5, 1.5, 2.0\} \tag{2a}$$

$$\overline{\overline{\mu}}_b^2 = diag\{1.0, 1.0, 1.5\} \tag{2b}$$

$$\overline{\overline{\sigma}}_b^2 = diag\{1, 1, 2\} \text{ mS/m} \tag{2c}$$

The transmitters and receivers are placed in the top layer and the concave arbitrary anisotropic object is buried in the bottom layer. Its dielectric parameters are listed in Table I. The detailed slices of the reconstructed results are shown in Fig. 2. We can see that not only the shapes are well reconstructed, but also the dielectric parameters are close to the true values listed in Table I. These good results show that the proposed VBIM-SCC algorithm can be used to reconstruct the arbitrary anisotropic scatterers embedded in layered media.

IV. CONCLUSION

In this paper, the VBIM-SCC is employed to reconstruct the 18 parameters of arbitrary anisotropic objects embedded layered uniaxial media. Numerical results show that not only the geometry shapes are precise but also the retrieved parameters are reliable. Future work will be focused on the anti-noise ability tests of our inversion algorithm, and the reconstruction of more complicated structures.

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