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SIMPLIFIED SCHEME TO SEPARATELY RETRIEVE PERMITTIVITIES OF SURFACES OF A DIHEDRAL STRUCTURE USING RADAR POLARIMETRY

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ABSTRACT

This paper presents a simplified scheme for complex permittivity inversion of a double bounce scattering using polarimetric measurements. A forward scattering model is employed to establish the relationship between the observed far field and the underlying permittivity profiles. An inversion scheme based on an approximation is then developed to separately obtain the complex permittivity values corresponding to the two surfaces that constitute a dihedral structure. Electromagnetic simulations demonstrate the effectiveness of the proposed method in accurately recovering the complex permittivity values. Using real airborne data provided by ONERA, the proposed scheme was then utilized to test the possibility of extracting the complex permittivity profiles from double bounce scattering signatures in PolSAR imagery. The obtained complex permittivity profiles exhibit a correlation with previous studies, indicating the reliability of the inversion scheme to study the inverse double bounce scattering problem.

Index Terms— Double bounce scattering, Permittivity inversion, Polarimetry, Synthetic Aperture Radar (SAR)

1. INTRODUCTION

THE signature of double bounce scattering is predominantly present in SAR images in the vicinity of man-made structures and forest borders and hence it is interesting to survey the possibility of obtaining information about the surfaces perpendicular to the ground, which are not easily interpretable in the imaging geometry. The possibility to separately retrieve permittivities of a dihedral structure using two independent measurements has been first demonstrated and extensively studied in [1][2]. The numerical scheme introduced in [2], page 51, referred to as the “Ratio method” is compelling for PolSAR but yields multiple solutions and hence needs a filter to identify the proper solutions. This poses a problem when this scheme is used to invert permittivities from RADAR measurements or from real SAR images where the ground truth is not known. Here we propose a simplified scheme based on an approximation that leads to

analytical solutions with less ambiguity for the inverse scattering problem of a dihedral structure.

2. THE SIMPLIFIED SCHEME

Using the forward model for the double bounce scattering in [3] and by considering the following co-pol ratio,

$$\rho^{DB} := \frac{S_{Vv}}{S_{Hh}} \quad (1)$$

the inverse problem can be cast into solving the following system according to [2], page 51,

$$p_i X_{1_i} X_{2_i} + q_i X_{1_i} + r_i X_{2_i} + s_i = 0 \quad (2)$$

with two independent measurements $i \in \{1, 2\}$ and,

$$\begin{aligned} p_i &= (\rho_i^{DB} - 1) \cos \psi_i \cos \zeta_i \\ r_i &= (\rho_i^{DB} + 1) \cos \psi_i \sin^2 \zeta_i \\ q_i &= (\rho_i^{DB} + 1) \sin^2 \psi_i \cos \zeta_i \\ s_i &= (\rho_i^{DB} - 1) \sin^2 \psi_i \sin^2 \zeta_i \end{aligned} \quad (3)$$

where ψ and ζ are incidence angles on the wall and ground respectively as in [3] and where X_{j_i} is considered as follows,

$$X_{j_i} = \sqrt{\epsilon_j - \sin^2(\theta_i)} \quad (4)$$

From Eq.(4), it can be noted that X_{j_1} and X_{j_2} are related in the following way:

$$X_{j_2}^2 + \sin^2(\theta_2) = X_{j_1}^2 + \sin^2(\theta_1) \quad (5)$$

Hence,

$$\begin{aligned} X_{j_2} &= X_{j_1} \left[1 + \frac{(\sin^2(\theta_1) - \sin^2(\theta_2))}{X_{j_1}^2} \right]^{1/2} \\ &= X_{j_1} \left[1 + \frac{1}{2} \frac{(\sin^2(\theta_1) - \sin^2(\theta_2))}{X_{j_1}^2} + \dots \right] \end{aligned} \quad (6)$$

The series expansion can be justified by observing that if $0 < \theta_1 < \theta_2 < \frac{\pi}{2}$, then $\sin \theta_1 < \sin \theta_2 < 1 < \text{Re}(\epsilon_j)$, and hence,

$$\frac{|\sin^2(\theta_1) - \sin^2(\theta_2)|}{|X_{j_1}^2|} < 1 \quad (7)$$

Based on Eq.(6), we propose the following approximation,

$$X_{j_2} \approx X_{j_1} \quad (8)$$

which then makes X_1 and X_2 in Eq.(2) independent of the index i . Hence, by considering the two cases $i \in \{1, 2\}$ in Eq.(2),

$$X_1 = -\frac{(r_1 X_2 + s_1)}{(p_1 X_2 + q_1)} = -\frac{(r_2 X_2 + s_2)}{(p_2 X_2 + q_2)} \quad (9)$$

Then from the second equality,

$$aX_2^2 + bX_2 + c = 0 \quad (10)$$

where,

$$\begin{aligned} a &= r_1 p_2 - r_2 p_1 \\ b &= s_1 p_2 - s_2 p_1 + r_1 q_2 - r_2 q_1 \\ c &= s_1 q_2 - s_2 q_1 \end{aligned} \quad (11)$$

Hence, finding the solutions to the inverse double bounce scattering problem can be re-stated as solving Eq.(9) and Eq.(10). An important consequence is that Eq.(10) also leads to a closed-form analysis of the solution space. Furthermore, the following criteria will be imposed on the solution space for the values to be physically interpretable.

$$\epsilon_1, \epsilon_2 \in \{\epsilon \in \mathbb{C} \mid [1 < \text{Re}(\epsilon)] \ \& \ [\text{Im}(\epsilon) < 0]\} \quad (12)$$

3. VALIDATION USING SIMULATIONS

We then simulated the double bounce scattering in FEKO [4] in order to test the inversion scheme. The CAD model in Fig.1 corresponds to ground dimensions $100 \text{ m} \times 100 \text{ m} \times 1 \text{ m}$ with permittivity $\epsilon_1 = 10 - 3i$ and to building dimensions $20 \text{ m} \times 20 \text{ m} \times 10 \text{ m}$ with permittivity $\epsilon_2 = 2.4 - 4.5i$.

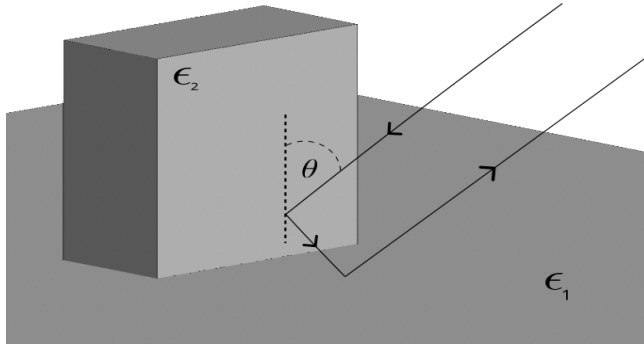
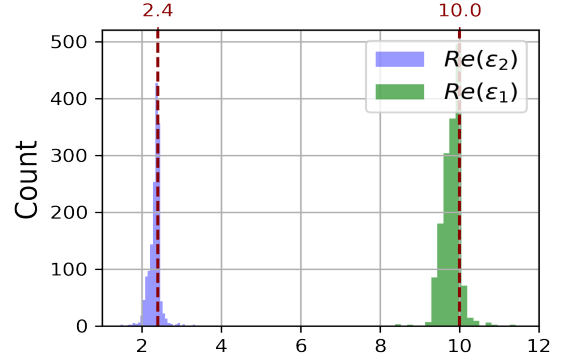
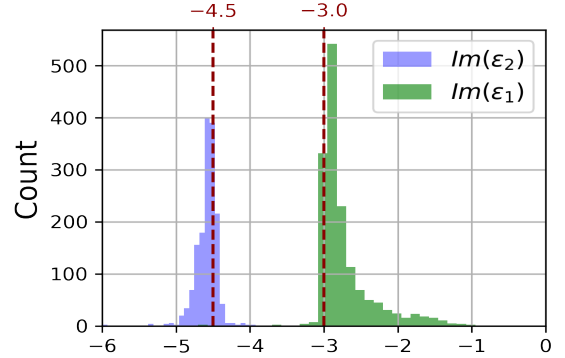


Fig. 1: CAD model used in FEKO illuminated by a plane wave at 1GHz with incidence $\phi = 0^\circ$ and $\theta \in [0^\circ, 90^\circ]$ using RL-GO

The structure was illuminated by a plane wave at 1GHz with incidence $\phi = 0^\circ$ and $\theta \in [0^\circ, 90^\circ]$ using RL-GO (Ray Launching Geometric Optics) method. In Fig.2b, we plot in a histogram the solutions obtained for each pair $\theta_1, \theta_2 \in [20^\circ, 70^\circ]$.



(a) Real part of inverted permittivity

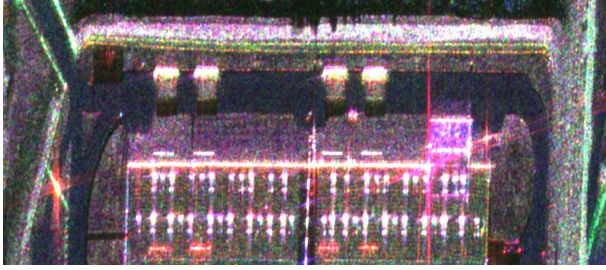


(b) imaginary part of inverted permittivity

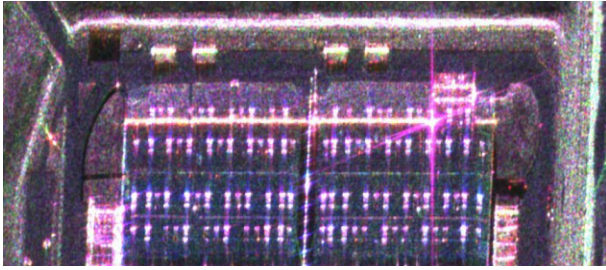
Fig. 2: Validation of the permittivity inversion scheme using simulations done with FEKO

4. A TEST ON REAL DATA

We test the proposed inversion scheme on a real data set from ONERA [5]. The resolution of the quad-pol images are 0.20 m in range and 0.50 m in azimuth and had been acquired in two incidence angles of 45° and 60° at X-band. The region of interest (ROI) contains a linear signature which is a ground/wall double bounce occurring from a building facade which is situated in the data set that had been acquired over Saint Martin-de-Crau, France.

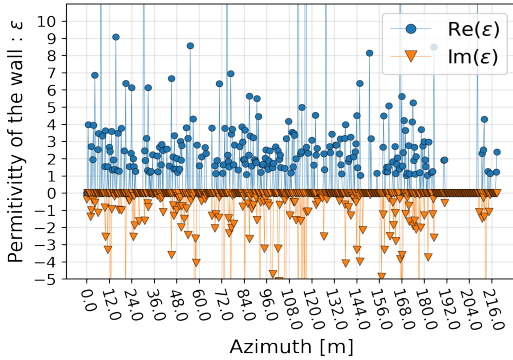


(a) Incidence angle : 60°

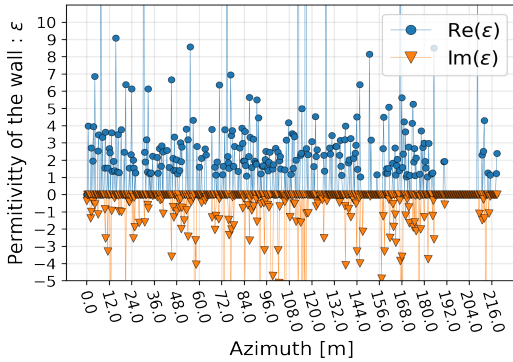


(b) Incidence angle : 45°

Fig. 3: ROI: X-band SLC with RGB colour coding. Red: Hh, Green: Hv and Blue: Vv



(a) Permittivity profiles for the wall obtained using the proposed inversion scheme



(b) Permittivity profiles for the ground obtained using the proposed inversion scheme

Fig. 4: Test on a real data set provided by ONERA

The obtained values seem to conform with that reported in [6]. The peaks occurring simultaneously on both the real and imaginary part of permittivity are speculated to be occurring from metallic structures on the wall. The location of some of these peaks coincides with the location of a ladder and doors which have been localized from ground observations.

5. CONCLUSION

The simplified scheme based on an approximation proposed here leads to analytical expressions for complex permittivity inversion from a double bounce scattering. Hence, it can be utilized to explore further the existence and stability of solutions for the general inverse double bounce scattering problem. By introducing a perturbation on ρ^{DB} , this simplified system can also be used to study the impact of speckle noise and roughness of the surfaces on the permittivity inversion from a double bounce scattering. Furthermore, it can be used as a filter to compress the ambiguity of the solution space obtained by using the ratio method in [2].

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