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# NUMERICAL SCHEMES TO RETRIEVE PERMITTIVITIES FROM ROTATED DOUBLE BOUNCE SIGNATURES IN POLARIMETRIC SAR IMAGES

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## ABSTRACT

In this paper, we propose an extension to an existing permittivity inversion scheme by taking into account double bounce scattering from a rotated dihedral geometry. By considering the rotational aspect, we aim to broaden the applicability of the permittivity inversion scheme for rotated double bounce signatures present in Synthetic Aperture Radar (SAR) imagery. The validity is first demonstrated by invoking to the characteristics of the co-pol ratio through simulations. The inversion scheme is then tested on real airborne SAR data to further validate its effectiveness in real-world scenarios.

*Index Terms*— SAR, Double bounce, Permittivity

## 1. INTRODUCTION

THE possibility to separately retrieve permittivities of a dihedral structure using two independent measurements has been first demonstrated and extensively studied in [1][2], where the dihedral possesses no rotation, i.e.  $\phi = 0^\circ$ . The numerical scheme introduced therein referred to as the “Ratio method” is compelling for PolSAR applications and however, in SAR images, we often find linear double-bounce signatures that occur because of rotated dihedral structures such as building facades [3] or dense forest borders, and hence, the above scheme needs to be extended to include rotation.



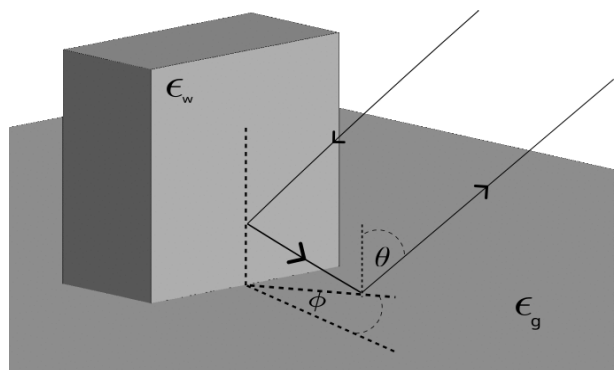
**Fig. 1:** A rotated double bounce signature in a SAR image, Top : X-band SLC image. Bottom : ground observation.

## 2. CHARACTERISTICS OF THE CO-POL RATIO FOR ROTATED DOUBLE BOUNCES

We start by studying the primary quantity that leads to the inversion which is the following co-pol ratio:

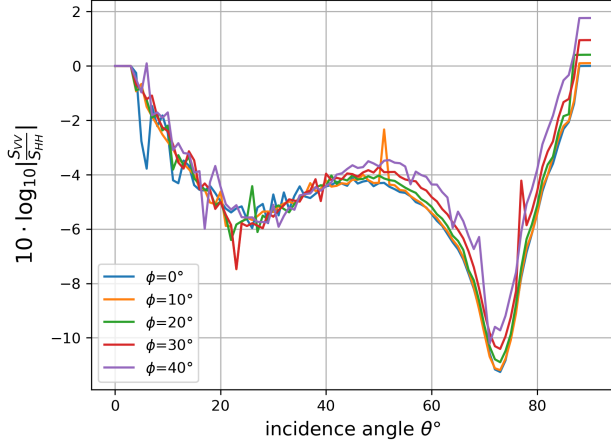
$$\rho^{DB} := \frac{S_{vv}}{S_{hh}} \quad (1)$$

where  $S_{vv}, S_{hh}$  are the diagonal elements of the Sinclair scattering matrix. In order to check the applicability of the ratio method in [2], we invoke the Lambertian scattering property of a dihedral geometry and check the reliability of the ratio in Eq.(1). In order to study the effect of rotation, we simulated the double bounce in FEKO [4] using the CAD model in Fig.2 which corresponds to a smooth ground of dimensions  $100 \text{ m} \times 100 \text{ m} \times 1 \text{ m}$  with permittivity  $\epsilon_1 = 10 - 3i$  and to a building with smooth walls of dimensions  $20 \text{ m} \times 20 \text{ m} \times 10 \text{ m}$  with permittivity  $\epsilon_2 = 2.4 - 4.5i$ .

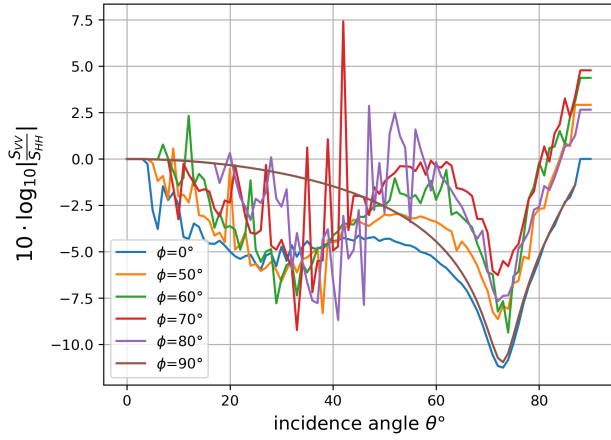


**Fig. 2:** CAD model used in FEKO

The structure was illuminated by plane waves at 1GHz with incidence angle  $\theta \in [0^\circ, 90^\circ]$  and for rotation angle  $\phi \in [0^\circ, 90^\circ]$  using RL-GO (Ray Launching Geometric Optics) method.



(a) Co-pol ratio for  $\phi \in [0^\circ, 40^\circ]$



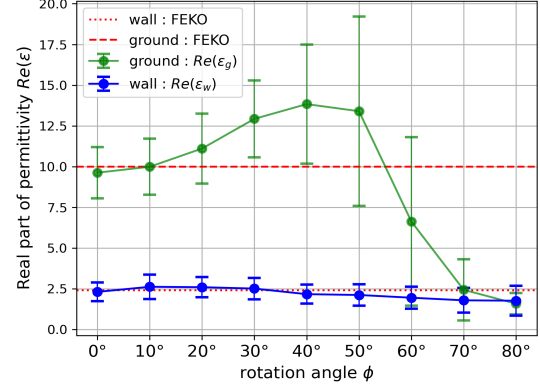
(b) Co-pol ratio for  $\phi \in [50^\circ, 90^\circ]$

**Fig. 3:** Simulations in FEKO

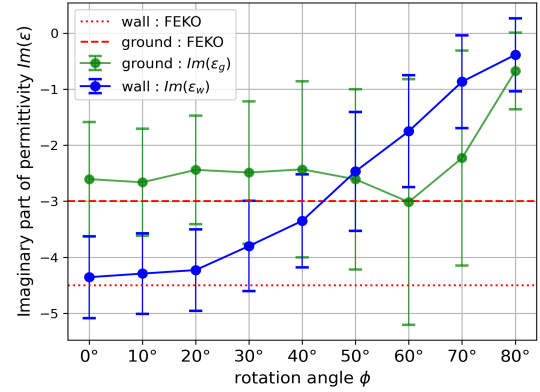
It can be seen from Fig.3a that for  $\phi \in (0^\circ, 40^\circ]$  the ratio follows the same characteristics as of  $\phi = 0^\circ$  and hence the double Brewster angle effect [5] is well preserved.

### 3. PERMITTIVITY INVERSION

In Fig.4a and Fig.4b we plot the mean and standard deviation of inverted permittivity values obtained for each pair  $\theta_1, \theta_2 \in [20^\circ, 70^\circ]$ . It can be seen that the real part of the wall is relatively well retrieved and in general, all the inverted values are reliable up to  $\phi = 30^\circ$ . What is of interest for  $30^\circ < \phi$  is the fact that the scheme yet produces a mean value with a finite standard deviation and hence its utility to study changes in permittivity can be speculated. It is particularly of interest for applications that require moisture retrieval.



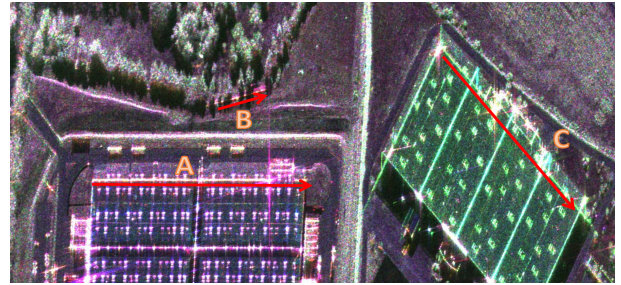
(a) Mean and standard deviation of the real part of inverted permittivity for all  $\theta_1, \theta_2 \in [20^\circ, 70^\circ]$



(b) Mean and standard deviation of the imaginary part of inverted permittivity for all  $\theta_1, \theta_2 \in [20^\circ, 70^\circ]$

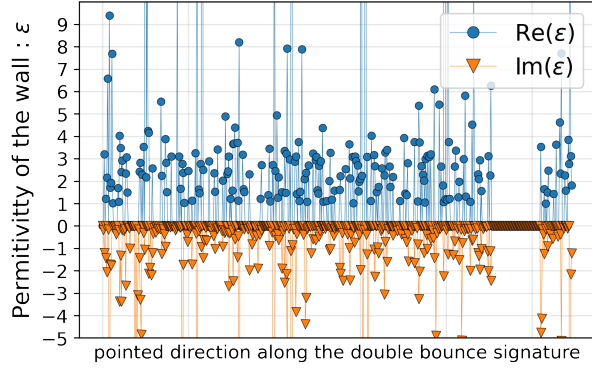
**Fig. 4:** Permittivity inversions obtained for simulations in FEKO

### 4. A TEST ON REAL AIRBORNE SAR DATA

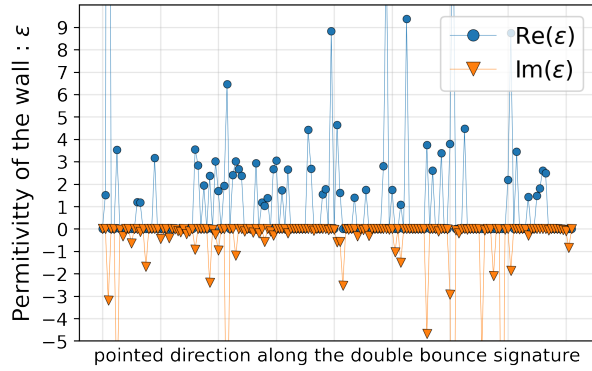


**Fig. 5:** X-band SLC at  $45^\circ$  incidence angle with RGB colour coding. Red: Hh, Green: Hv and Blue: Vv

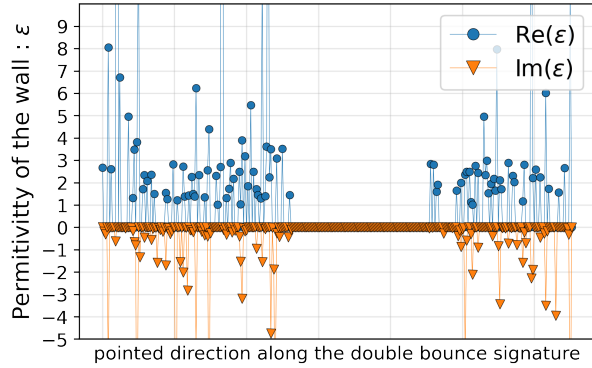
We then test the inversion scheme on a real data set from ONERA [6][7]. The resolution of the quad-pol images are 0.20m in range and 0.50m in azimuth and had been acquired in two incidence angles of  $45^\circ$  and  $60^\circ$  at X-band over Saint Martin-de-Crau, France.



(a) Double bounce A :  $\phi \approx 0^\circ$



(b) Double bounce B :  $\phi \approx 10^\circ$



(c) Double bounce C :  $\phi \approx 34^\circ$

**Fig. 6:** Test on a real data set provided by ONERA

It is interesting to compare the values corresponding to the double bounces A and C since the buildings are warehouses of a similar type. The distribution of the imaginary part of permittivity in Fig.6a and Fig.6c seems to conform to the predicted lowering in Fig.4b and the distribution of the real part seems to be between 2-4. The relative peaks are speculated to be occurring from metallic structures present on the wall which should be confirmed by geolocating them once more ground truth is available.

## 5. CONCLUSION

The presence of the double Brewster effect for dihedrals with  $\phi \in [0^\circ, 40^\circ]$  has been observed in simulations. The validity of the ratio method in [2] was investigated as an permittivity inversion scheme for scattering from rotated dihedrals and was validated using simulations. It has further been tested along with real airborne PolSAR data. Further ground truth and permittivity measurements are required to establish an interpretation for the inverted values.

## 6. REFERENCES

- [1] Orian Couderc, Laetitia Thirion-Lefevre, and Régis Guinvarc'h, "Analytical solution for permittivities of a dihedral configuration," *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 3, pp. 485–488, 2018.
- [2] Orian Couderc, *Permittivities retrieval of a dihedral structure using radar polarimetry*, Ph.D. thesis, Université Paris Saclay (COMUE), 2019.
- [3] Régis Guinvarc'h and Laetitia Thirion-Lefevre, "The signature of rotated double bounces in urban areas," in *2015 IEEE 5th Asia-Pacific Conference on Synthetic Aperture Radar (APSAR)*. IEEE, 2015, pp. 462–465.
- [4] "Altair FEKO, Altair Engineering," <https://www.altair.com/feko>.
- [5] Laetitia Thirion-Lefevre and Régis Guinvarc'h, "The double Brewster angle effect," *Comptes Rendus Physique*, vol. 19, no. 1-2, pp. 43–53, 2018.
- [6] Rémi Baqué, Olivier Ruault Du Plessis, Nicolas Castet, Patrick Fromage, Joseph Martinot-Lagarde, Jean-François Nouvel, Hélène Oriot, Sébastien Angelliaume, Frédéric Brigui, Hubert Cantalloube, et al., "SETHI/RAMSES-NG: New performances of the flexible multi-spectral airborne remote sensing research platform," in *2017 European Radar Conference (EURAD)*. IEEE, 2017, pp. 191–194.
- [7] Steve Tyler, Xavier Dupuis, Régis Guinvarc'h, and Laetitia Thirion-Lefevre, "A first test on permittivity inversion of a double bounce in a SAR image," in *IGARSS 2022-2022 IEEE International Geoscience and Remote Sensing Symposium*. IEEE, 2022, pp. 5668–5671.