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# Double bounce mechanism and deterministic targets in SAR remote sensing

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## Abstract

The Double Bounce scattering mechanism is usually compared to the ideal polarimetric response of a metallic dihedral reflector, for instance in the Pauli basis. This is however only valid for perfect metallic targets, perfectly aligned with the sensor. When rotated, the double bounce mechanism gives both a double bounce electromagnetic response (VV and HH) and a crosspolarization response. This paper focuses on this and illustrates its use.

The comparison of the double bounce mechanism with a metallic dihedral is convenient and used in many decompositions. This comparison is however only valid under two strong assumptions: for perfect metallic target and perfectly aligned with the sensor trajectory.

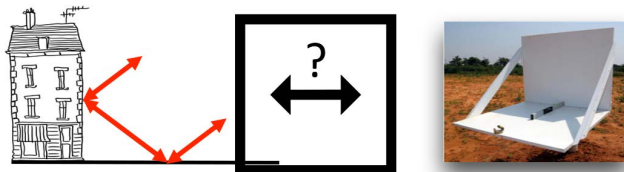


Figure 1 Is it true?

## 1 Effect of the orientation

Physically, the cross-pol contribution is theoretically null if the scene is symmetric and if the incident plane includes an axis of symmetry of the scene. Figure 2 plots the variation of the polarimetric backscattering coefficients of a perfectly metallic dihedral (1m side at C-band with FEKO Method of Moments [1]) with the azimuth angle. When perfectly aligned, VV is equal to HH and HV is almost null. Even for a slight misalignment (few degrees), HV increases a lot. In reality, HV value is either exceptionally low for deterministic and metallic targets properly oriented and quite low for natural targets with randomly oriented facets or scatterers, as sea surfaces or forests.

Cross-polarization is often used as the signature of quasi-random volume such as forest canopies. It is also the signature of man-made targets when they are not perfectly aligned with the sensor trajectory. As such, it often leads to ambiguity, for instance in the Pauli representation. But it is indeed a good way to detect and analyze determin-

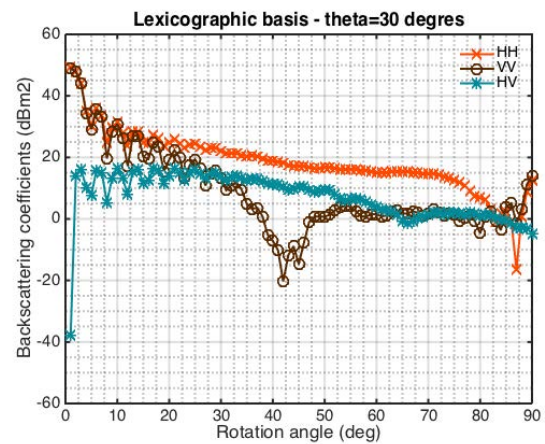
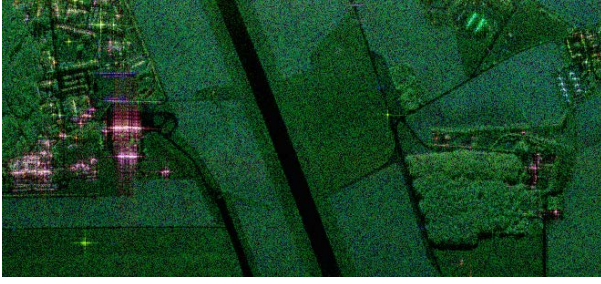


Figure 2 Signature of a metallic dihedral with respect to the azimuth angle

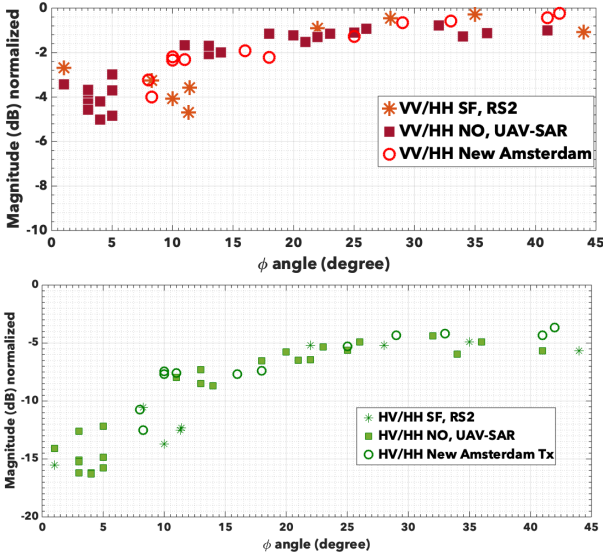
istic targets. The cross-pol intensities are often low and barely used, except for some very specific applications. For instance, they are studied to estimate the quality of the calibration of a radar sensor [2] as it is expected to have  $VH=HV$  in intensity because of reciprocity. Their values are also generally used as a signature of quasi-random volume as forest canopies. Therefore, their value - normalized by the span or by the maximum intensity for instance - are used in the Pauli decomposition to represent the contribution of vegetation. However, it is well known now that this too simple classification can lead to errors. Thus, cross-polarization values can also be an indication of slanted buildings for instance [3].

## 2 Effect of material

In [4], the effect of dielectric on polarization was investigated. In particular, for the case of the double bounce mechanism, it was shown that VV (and only VV) was lowered by the so called Double Brewster angle Effect (DBE);



**Figure 3** Signature of a metallic dihedral with respect to the azimuth angle



**Figure 4** VV/HH (top) and HV/HH (bottom) variations with the azimuth angle for several cities/sensors

it is two Brewster angles, one for the reflection of each face of the dihedral, occurring at two complementary angles. The consequence is that for most dielectric materials (concrete, wood, sand etc.), VV is lowered by up to 10 dB because of these reflections on dielectric materials. HH is unaffected.

### 3 Combined effect of rotation and material

Figure 3 shows a SAR image from ONERA at X band. This is in the Pauli basis, double bounce in red, single scattering in blue and cross-polarization in green. In the middle left, there are two large dielectric buildings aligned with the sensor, while on the top right there are two dielectric buildings rotated by about 45 degrees. The first two sign in pink (not red) and show a strong DBE effect, with HH larger than VV by more than 20 dB and VH small. On the contrary, for the misaligned buildings VV is roughly equal to HH with a strong VH signal. They sign in green in the Pauli representation. It is also interesting to note a significant DBE effect on the northern edge of the forest (double bounce road-trunk). Here it shows two significant different behaviours for dielectric buildings, depending on

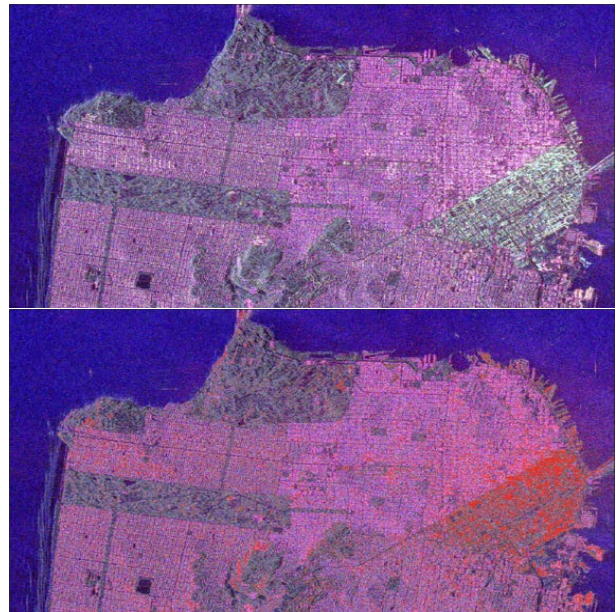
the alignment with the sensor (and so the symmetry of the scene).

## 4 Some examples

### 4.1 Illustration on cities

The polarimetric ratios VV/HH, HV/HH are particularly meaningful. Recently [5], we have highlighted that for two US cities the angular variation of these ratios remains the same whatever the sensor - airborne or space borne - and the frequency; L and C bands have been tested. In addition, it reaches a value which is comparable to those obtained for forests. The ambiguity between vegetation and rotated buildings may actually be related to these ratios instead of the value of the cross-pols alone. Figure 4 shows the polarimetric ratio for various districts as a function of the orientation angle of the district with respect to the sensor trajectory. We have three cities: San Francisco, acquired by RS2 (so C band), New Orleans acquired by UAVSAR and Amsterdam by TerraSAR X. For small orientation angle, we have always VV inferior to HH because of the DBE effect, whatever the cities, whatever the district (so concrete buildings as well as wooden structures). In a second part, VV tends to HH as DBE disappears.

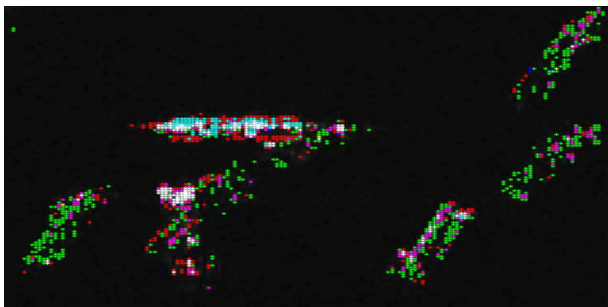
An implication relies in this difference that we can observe between natural and man-made environments. For the RS2 image of San Francisco used in Fig. 5, decomposition techniques face a issue with quarter of SOMA, which is disoriented by about 37 degrees from the sensor trajectory. In the Pauli representation, it appears as forested areas. Using the fact that man made scatterers in a pixel can add in phase (as they are coherent), whereas natural scatterers are random, this quarter was successfully corrected in [3].



**Figure 5** SAR images of San Francisco acquired by RADARSAT-2 (FQ9 mode) in the classical Pauli basis representation (top) and with correction (bottom)

## 4.2 Illustration on ships

A second example is shown with ship detection, in UAVSAR images. A ship can be seen as a large dihedral, rotated for most of them. Figure 6 shows for 7 different polarimetric combinations which one gives the best detection for each pixel. This best polarimetric combination is coded by a color on the SAR image. Considering the results, the best results are precisely obtained for HV only with 48% of detection (except for one ship which is aligned with the sensor trajectory). Considering the copolarization, HH (21%) gives much better results than VV (1%), this is expected because DBE lowers VV. Considering the combination of HH and VV (16%), it is slightly worse than HH only as VV pollutes the results.



**Figure 6** Ship detection on UAVSAR quad pol images. Legend: HH only (red), HV only (green), VV only (blue), HH and VV (pink), HH and HV (yellow), VV and HV (light blue), HH, HV and VV (white)

## 5 Literature

- [1] <https://altairhyperworks.com/product/FEKO>
- [2] R. Touzi and M. Shimada, "Polarimetric PALSAR Calibration," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 47, no. 12, pp. 3951-3959, Dec. 2009.
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- [4] L. Thirion-Lefevre, and R. Guinvarc'h, "The double Brewster angle effect", in *Comptes Rendus Physique*, Elsevier, vol. 19, no. 1-2, 2018.
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