Polarimetric response for target characterization

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ABSTRACT: In this paper we propose the polarimetric response in target characterization and SAR radar image classification.

Polarimetric response is a graphical representation that is dependent on transmitted and received polarizations. The polarimetric response is given in a pair of two curves, one represents the co-polarized response and the second represents the cross-polarized response.

The fully polarimetric data is a combination of linear polarizations (HH, HV, VH and VV). This data must be structured in the form of 2×2 complex matrix known as the scattering matrix.

The generation of polarimetric response needs the knowledge of the scattering matrix. It is called polarization synthesis. In this paper we give different polarimetric responses that characterize canonical targets such as the dihedral or the sphere as well as the polarimetric response of distributed targets such as forests.

1 INTRODUCTION

Polarimetric SAR responses first introduced by Van Zyl (Ulaby & Elachi 1990), are an effective way to characterize the polarization properties of microwave backscattering. These responses have been used to classify terrain types (J.Van Zyl 1989), to measure terrain slopes (Schuler et al. 1996), used in the polarimetric interferometry SAR to identify the existence of independent scattering mechanisms inside the same resolution cell (Sagués et al. 2001). In this paper, we introduce the polarization plot used as a tool for polarimetric data to retrieve information on the scattering process of the target. The polarization plots capture many scattering characteristics of the target at all polarization. The shape of these plots is significant and can indicate the scattering mechanisms dominating the target response. The polarimetric response of a given pixel is often a result of a mixture of scattering mechanisms such as surface scattering, double-bounce or/and multiple scattering.

In Figure 1 we can notice direct backscatter from forest branches(1), direct backscatter from trunks(2), direct backscatter from ground(3), double-bounce scattering from trunks and ground(4), and double-bounce scattering from branches and ground(5). The polarimetric response is interpreted according to the contributing scatterers.

2 POLARIMETRIC RESPONSES THEORY

Fully polarimetric SAR systems transmit and receive both horizontal and vertical waves. This allows to measure the radar cross section (RCS) of the illuminated target that characterizes the backscattering property of the target: its size, shape, and orientation.
The technique of polarization synthesis can be used to simulate the backscattering response (RCS) for any arbitrary combination of transmit and receive polarizations, and it can be expressed in terms of the Kennaugh matrix (J. Van Zyl 1989), (I. H. Woodhouse 2002) as

\[ \sigma(\chi, \psi) = \frac{4\pi}{k^2} S_r KS_r^T \]  

where \( k \) is the transmitted wave number, and \( S \) is the normalized Stokes vector defined as

\[ S = [1 \cos(2\psi) \cos(2\psi) \sin(2\psi) \cos(2\chi) \sin(2\chi)]^T \]  

with the subscripts \( r \) and \( t \) denoting the received and transmitted polarizations, and \( T \) represents the transpose. In this definition \( \psi \) is the orientation and it is ranging from 0° to 180° angle. The \( \chi \) is the ellipticity angle and is ranging from -45° (right_hand circular polarisation) to 45° (left_hand circular polarisation) and \( K \) is the Kennaugh matrix given by:

\[ K = R^{-1}WR^{-1} \]  

\( R^{-1} \) is the inverse of \( R \) which is given by

\[
R = \begin{bmatrix}
1 & 1 & 0 & 0 \\
1 & -1 & 0 & 0 \\
0 & 0 & 1 & 1 \\
0 & 0 & -i & i \\
\end{bmatrix}
\]  

\( W \) is written as

\[
W = \begin{bmatrix}
S_{vv}^* & S_{vh}^* & S_{ih}^* & S_{vi}^* & S_{vi}^* \\
S_{bh}^* & S_{bb}^* & S_{ih}^* & S_{vi}^* \\
S_{iv}^* & S_{vb}^* & S_{ih}^* & S_{vi}^* \\
S_{sv}^* & S_{ih}^* & S_{ib}^* & S_{sv}^* \\
\end{bmatrix}
\]  

3 VISUALIZATION OF POLARIMETRIC SIGNATURE

To visualize the variations of radar cross section as function polarization states, a three dimensional graphical representation can be plotted to characterize the target responses at linear, circular, and
elliptical polarized configuration. The plot displays a backscatter cross section \((\chi, \psi)\) of one pixel or an averaged collection of pixels (Region of Interest) as a function of the \(\psi\) and \(\chi\) angles of the waves transmitted to and scattered back from the target. Circular polarizations have ellipticity angles of 45° with the sign of the ellipticity angle indicating the handedness or direction of rotation of the wave. Negative values indicate right-handed polarizations and positive values indicate left-handed polarizations. Linear polarizations have an ellipticity angle of 0°. Although all orientations are represented in the plot, the commonly used polarizations have orientation angles of 0° (H:Horizontal) or 90° (V:Vertical). In all the polarization response plots presented, the maximum of the backscattered intensity has been normalized to a value of 1.0.

Although many targets can produce similar plots, the shape of the plots as well as the pedestal height provides clues about the type of scattering dominant from the target.

4 SIMPLE TARGET POLARIZATION RESPONSES

The polarization response diagrams made by Kennaugh matrices for each simple target are shown in Figures 2 and Figure 3.

![Polarization response of a sphere, and trihedral corner reflector.](image)

Figure 2 shows the polarization responses of a large conducting sphere, trihedral corner reflector, or flat surface. The copolarized response shows that the maximum measured scattering cross section occurs for linear polarization and the scattering cross section is independent of the linear polarization orientation angle. For the cross-polarized response, the measured scattering cross section is greatest for the circular polarizations and smallest for linear polarizations.

The polarization responses of the two kinds of helices are shown in Figure 3 in each case, the maximum in the co-polarized response occurs at the circular polarization, the coupling between the incident wave electric field and the helix is maximum. The scattered wave is circularly polarized with the same handedness as the incident wave, which means that the scattered wave and the receiving antenna have the same polarization in the co-polarized, leading to the observed maximum in the response. In the case of the cross-polarized responses the two kinds of helices are identical. This means that the handedness of the helix cannot be deduced from the cross-polarized response, but easily deduced from the co-polarized response.
DISTRIBUTED TARGET POLARIMETRIC RESPONSE

As an example of experimental responses, data sets were collected during an DLR’s airborne campaign E-SAR in 2001 above Wessling, in the Oberpfaffenhofen area, Munich, Germany. Figure 4 gives the test site with different selected regions. Figure 5 displays the copolar and crosspolar responses of the regions selected in the test site. These regions are for urban, forest, vegetation, and smooth surfaces.

Figure 5a fits well to the even-bounce scattering of horizontal dehidrals which correspond to the building ground interaction. In Figure 5b the polarization responses denote the helix scattering mechanisms which represent the scattering response of an agriculture field. The response of the first type of forest shown in Figure 5c indicates a dominant dipole scattering mechanism oriented at 45°. The second type of forest shown in Figure 5d is dominated by a dipole scattering target oriented vertically. In Figure 5e which represents the polarimetric response of the runway, the graphs are similar to that of the trihedral scattering type.

Figure 3. (a) Polarization response of a left-handed helix; (b) Polarization response of a right-handed helix.
6 CONCLUSION

The potential of the polarimetric data to discriminate targets was investigated in this study. Extraction of polarimetric responses was used to interpret and recognize the scattering mechanisms of different natural and man-made targets. Both the copolar and crosspolar responses are powerful tools to provide information on the dominant scattering mechanism. In the region of interest chosen, further work will be done in polarimetric SAR classification and validation will be done using the polarimetric responses.

Figure 4. RGB image of the Oberpfaffenhofen region Red: HH-VV, Green: HV, Blue: HH+VV.

Figure 5. (a) DLR building.
Figure 5. (b) Agriculture field.

Figure 5. (c) Classe 1 Forest.

Figure 5. (d) Classe 2: Forest.
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REFERENCES


