Three-Component Scattering Power Decomposition Method with Phase Rotation of Coherency Matrix

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Abstract

This paper presents a new three-component scattering power decomposition method by using phase rotation of coherency matrix and extending volume scattering model. This new method shows accurate decomposition of fully polarimetric SAR data as compared the existing power decomposition methods.

Keywords : Radar Polarimetry Scattering Power Decomposition Coherency Matrix Phase Rotation

1. Introduction

Scattering power decompositions have been a topical issue in radar polarimetry for the analysis of fully polarimetric synthetic aperture radar data [1], [2]. There exist 9 real independent observation parameters in a 3 x 3 coherency or covariance matrix as the second order statistics of polarimetric information. The original 3-component decomposition was proposed by Freeman and Durden [3] under reflection symmetry condition that the cross-correlation between the co- and cross-polarized scattering elements are close to zero for natural distributed objects, i.e., $\langle S_{HH} S^*_{HV}\rangle \approx \langle S_{VV} S^*_{HV}\rangle \approx 0$. This method accounts 5 parameters in the decomposition out of 9 independent parameters, leaving 4 parameters un-counted. By phase rotations of coherency matrix using unitary transformation, it is possible to reduce the number of independent parameters from 9 to 8, leaving 3 un-counted. Phase rotations have been used to eliminate the helix scattering source in the 4-component decomposition [4], resulting in a new 3-component decomposition. In addition, an extended volume scattering model has been employed, which discriminates the volume scattering between dipole and dihedral scatterings caused by the cross-polarized *HV* component. This new three-component decomposition accounts 5 parameters out of 8 independent polarimetric parameters existing in the coherency matrix. It is found that this method yields accurate decomposed images compared with those by existing scattering power decomposition method [3] - [5] with easy calculation.

2. Coherency Matrix

If scattering matrix data set is acquired, the corresponding coherency matrix can be created, which retains the second order statistics of polarimetric information. The ensemble average of the coherency matrix is given as

$$[T] = \left\langle \boldsymbol{k}_p \boldsymbol{k}_p^{\dagger} \right\rangle = \begin{bmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{bmatrix} \tag{1}$$

where † denotes complex conjugation and transposition, < > denotes ensemble average, and the Pauli vector $\boldsymbol{k_p}$ is defined as

$$\boldsymbol{k}_p = \frac{1}{\sqrt{2}}\begin{bmatrix} S_{HH}+S_{VV} \\ S_{HH}-S_{VV} \\ 2S_{HV} \end{bmatrix} \tag{2}$$

where S_{HH}, S_{VV}, S_{HV} are elements of the scattering matrix **S** [2]**.**

Unitary transform does not change the information contained in the coherency matrix. Using this mathematical property, It can be attempted to rotate the measured coherency matrix (1) to a new one with $Im\{T_{23}\}$=0.
T_{23} can be written in terms of scattering matrix as

$$T_{23} = \left\langle \left(S_{HH} - S_{VV}\right) S_{HV}^{*} \right\rangle \tag{3}$$

Since the element $Im\{T_{23}\}$ is the source of helix scattering power in the coherency matrix, the helix power vanishes after the elimination of $Im\{T_{23}\}$ in the four-component decomposition [4],[5], resulting in three scattering powers (surface scattering power P_s, double bounce power P_d, and volume scattering power P_v). In order to achieve $Im\{T_{23}\}$=0, It is required phase unitary transformations (It is shown in next section).

3. New Three Component Scattering Power Decomposition

In this section, a new three-component scattering power decomposition is explained using the rotated coherency matrix (3). The three-component powers represent surface scattering power P_s, double bounce scattering power P_d, and volume scattering power P_v, as shown in Fig.1 which are well known in many literatures [1]-[5].

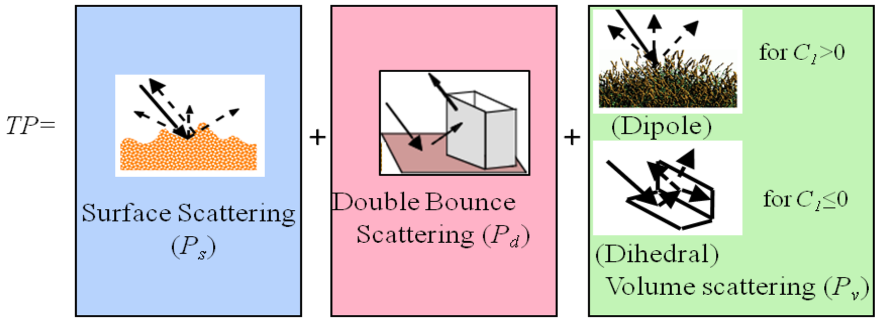

Fig. 1. New three-component scattering mechanism for decomposing total power (*TP*) into scattering powers (P_s, P_d, and P_v), where C_1= T'_{11}- T'_{22}.

The flow-chart of new 3-component scattering power decomposition algorithm is shown in Fig. 2. In the first stage before decomposition, phase rotation has been implemented to the measured coherency matrix to make $Im\{T_{23}\}$=0. Then the 3-component decomposition scheme is carried out. Then we check the sign of branch condition C_1 for assigning *HV* component is denoted as $T'_{11} > T'_{22}$. After the volume scattering power determination, it is possible to critically determine the dominant scattering mechanism within the volume scattering by dipole. For this purposed, we check the second branch condition using (5) to confirm the scattering mechanism [4].

$$C_0 = 2\,\mathrm{Re}\left\{f_s\,\beta + f_d\,\alpha^*\right\} = 2\,\mathrm{Re}\left\{\left\langle S_{HH}S_{VV}^{\;*}\right\rangle\right\} - 2\left\langle\left|S_{HV}\right|^2\right\rangle = T'_{11} - T'_{22} - T'_{33} \tag{5}$$

The number of independent parameters in the coherency matrix are reduced from 9 to 8 by phase rotation. This new decomposition counts 5 parameters out of 8.

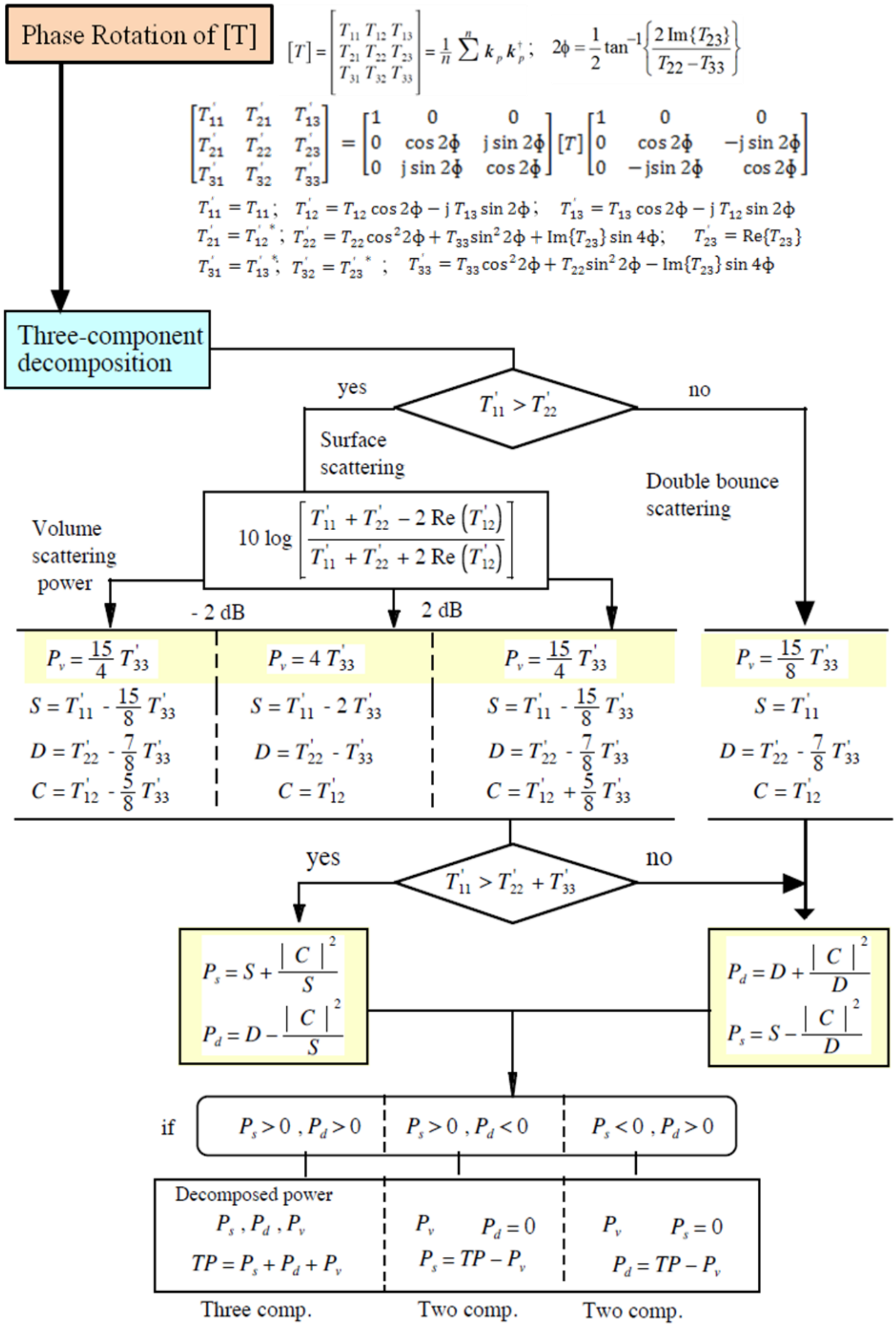

Fig. 2. Flow-chart of new three-component scattering power decomposition.

4. Decomposition Results

This new three-component decomposition scheme is applied to TerraSAR-X quad-pol. single look slant range complex (SSC) image. Fig. 3 shows Part of Niigata image acquired on April 21, 2010, and compares the existing methods derived in [3]-[5] with the presented new method. It is seen that the double bounce scattering power P_d (Red) is rather enhanced in (e) than in (b) to (d). This is because the *HV* component is assigned to the dipole scattering in (b) to (d) and to the dipole and dihedral scattering in (e), in addition to the minimization of T_{33} component served to the maximization of T_{22} component by phase rotation. The interesting observation relates to oriented urban area of images. The green color of the oriented urban area in (b) to (d) is suppressed in (e). We can recognize that this area is made up of man-made structures because of so many scattered red spots.

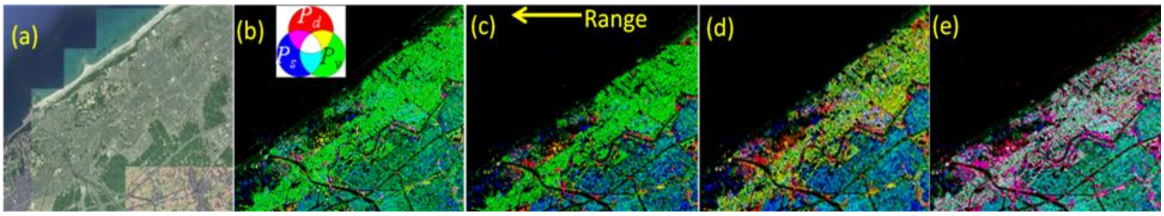

Fig. 3. (a) Google earth image (b) Freeman and Durden method [3], (c) Four-component decomposition [4], (d) Modified four-component decomposition [5], (e) Present method (new three-component decomposition).

This new three-component decomposition scheme is applied to many ALOS-PALSAR quad-pol. level 1.1 images for verifying the correct implementation of this scheme. It is found that proposed method reduces the volume scattering power and enhances the double bounce scattering power within man-made structures. However this method does not change the amount of volume scattering in forest and vegetation area.

Acknowledgments

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