OPTIMUM POLARIZATION CONCEPT FOR POLARIMETRIC CLUTTER SUPPRESSION

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Abstract

Kennaugh's target characteristic operator theory for the single scatterer case expressed in terms of the 2x2 radar scattering matrix is generalized for polarimetric description of clutter, i.e., distributed multiple scatterer ensemble, in terms of the mean co-polarization and mean cross-polarization nulls and their spread and depth about the mean values using the coherency/Mueller matrix formulations.

Introduction

In radar polarimetry, one treats a specific radar clutter target by a certain model. The radar clutter targets can be very complicated structures (e.g. sea state, terrain, etc.). Even if one has well analyzed a model, the results thus obtained cannot, in general, be used for another model; so, there is a need to develop a model-free clutter descriptive theory that can be applied for any types of clutter. In what follows, we develop a model-free clutter model based on the optimum polarization concept.

Polarimetric Clutter Model

The backscattered radiation from a clutter target (e.g. hydrometeors and rough surfaces) is, in general, partially polarized. The partially polarized signal is represented by the coherency matrix or Stokes vector. The Kennaugh's optimal polarization theory of a single scatterer case can be extended to a random distribution of scattering centers (clutter) based on the coherency matrix.

1. Optimal Polarizations for Clutter Target

Optimal polarizations are the polarizations those result zero return in the receiving channels. If the zero return is in the co-pol channel, it will be termed as co-pol null. If the zero return is in the cross-pol channel, it will be termed as cross-pol nulls (See Boerner et.al. [1981] for detailed dimensions). The co-pol and cross-pol nulls can be calculated in terms of the ensemble averaged scattering matrix elements using the coherency matrix [Nespor et.al., 1983 and McCormick and Hendry, 1984] and they are given by,

1.A Co-Pol Nulls:

$$\bar{\rho}_{co} = \frac{-\overline{S_{12}} \pm \sqrt{\overline{S_{12}}^2 - \overline{S_{11}}\ \overline{S_{22}}}}{\overline{S_{22}}} \tag{1}$$

1.B Cross-Pol Nulls:

$$\bar{\rho}_x = \frac{-\bar{B} \pm \sqrt{\bar{B}^2 - 4\bar{A}\bar{C}}}{2\bar{A}} \tag{2}$$

where,

$$\overline{A} = \left(\overline{S_{22}} \ \overline{S_{12}^*} + \overline{S_{11}^*} \ \overline{S_{12}} \right)$$

$$\overline{B} = - \left(\overline{|S_{22}|^2} - \overline{|S_{11}|^2} \right)$$

$$\overline{C} = -A^*$$

2. Mean and Variances of the Optimal Polarizations

The returns from a clutter target when optimal polarizations are transmitted are minima rather than zero [McCormick and Hendry, 1984]. The minimas are described by the mean, spread and depth of the optimal polarizations. The mean values of the optimal polarizations are $\overline{\rho}_{1co}$, $\overline{\rho}_{2co}$, $\overline{\rho}_{1x}$, and $\overline{\rho}_{2x}$ as given by equations (1) and (2). These values are represented by the four points on the surface of the Poincaré sphere as shown in the figure.

The degree of polarization, P, for the partially polarized backscattered signal will have different values for all the four polarization nulls, i.e., P_{1co}, P_{2co}, P_{1x} and P_{2x} corresponding to $\overline{\rho}_{1co}$, $\overline{\rho}_{2co}$, $\overline{\rho}_{1x}$ and $\overline{\rho}_{2x}$, respectively. Thus the spread and depth corresponding to each of the polarization nulls are given by

2.A Spread:

$$\sigma_{1co} \simeq \frac{1}{2} \sqrt{1 - P_{1co}^2} \ , \ \sigma_{2co} \simeq \frac{1}{2} \sqrt{1 - P_{2co}^2} \tag{3}$$

$$\sigma_{1x} \simeq \frac{1}{2} \sqrt{1 - P_{1x}^2} \ , \ \sigma_{2x} \simeq \frac{1}{2} \sqrt{1 - P_{2x}^2}$$

2.B Depth:

$$d_{1co} \simeq \frac{1 - P_{1co}^2}{4} \ , \ d_{2co} \simeq \frac{1 - P_{2co}^2}{4} \tag{4}$$

$$d_{1x} \simeq \frac{1 - P_{1x}^2}{4} \ , \ d_{2x} \simeq \frac{1 - P_{2x}^2}{4}$$

The mean values represent an averaged single target. The spread and depth of the nulls represent the random nature of the clutter target.

3. Optimal Polarizations in Terms of Average Mueller Matrix Elements

The 4x4 real average Mueller matrix $[M_m]$ for a clutter target in terms of the 4x1 Stokes vectors for scattered and incident signals is defined as [Huynen, 1970]:

$$\underline{g}_m^s = [\overline{M}_m] \ \underline{g}_m^i \tag{5}$$

where g_m^s and g_m^i represent the partially polarized and completely polarized

signals, respectively.

According to Huynen's distributed target decomposition theorem [Huynen, 1970], a clutter target can be decomposed as:

$$[\overline{M}_m(9)] = [M'_m(5)] + [\Delta M(4)] \tag{6}$$

where $[M'_m(5)]$ represents an averaged single target and ΔM represents the residue target, i.e., the random behavior of the clutter target. In the calculation of the mean values of the co-pol and cross-pol nulls from the average Mueller matrix elements, we assume that

$$[\overline{M}_m] \approx [M'_m] = [\overline{S}] \tag{7}$$

Hence, the average scattering matrix elements in terms of the average Mueller matrix elements are given by [Boerner, et al, 1981]:

$$|\overline{S_{11}}| \approx \sqrt{M_{11}} \quad , \quad \overline{\Phi}_{11}=\overline{\Phi}_{12} - \tan^{-1}\frac{M_{14}}{M_{13}}$$

$$|\overline{S_{12}}| = |\overline{S_{21}}| \approx \sqrt{M_{12}} \ , \quad \overline{\Phi}_{12}=\overline{\Phi}_{21} \text{ is arbitrary (may be equal to zero)}$$

$$|\overline{S_{22}}| \approx \sqrt{M_{22}} \quad , \quad \overline{\Phi}_{22}=\overline{\Phi}_{12} - \tan^{-1}\frac{M_{42}}{M_{32}} \tag{8}$$

Substituting equation (8) into equations (1) and (2), the mean values of co-pol and cross-pol nulls can be calculated. For calculating the spread and depth of the nulls the degree of polarization corresponding to each of the polarization nulls can be calculated using the equation (5) and is expressed by the following equation:

$$P = \sqrt{\frac{(g^s_{m0} - g^s_{m1})^2 + {g^s_{m2}}^2 + {g^s_{m3}}^2}{(g^s_{m0} + g^s_{m1})^2}} \tag{9}$$

4. Applications

In general, the theory developed is applicable for any types of clutter (e.g. rain, snow, hail, cloud, chaff, sea surface, terrain, vegetative, etc.). For different types of clutter, the mean, spread and depth of the polarization nulls may have different values on the Poincaré sphere. Based on this fact, a classification scheme for the clutter versus clutter could be suggested.

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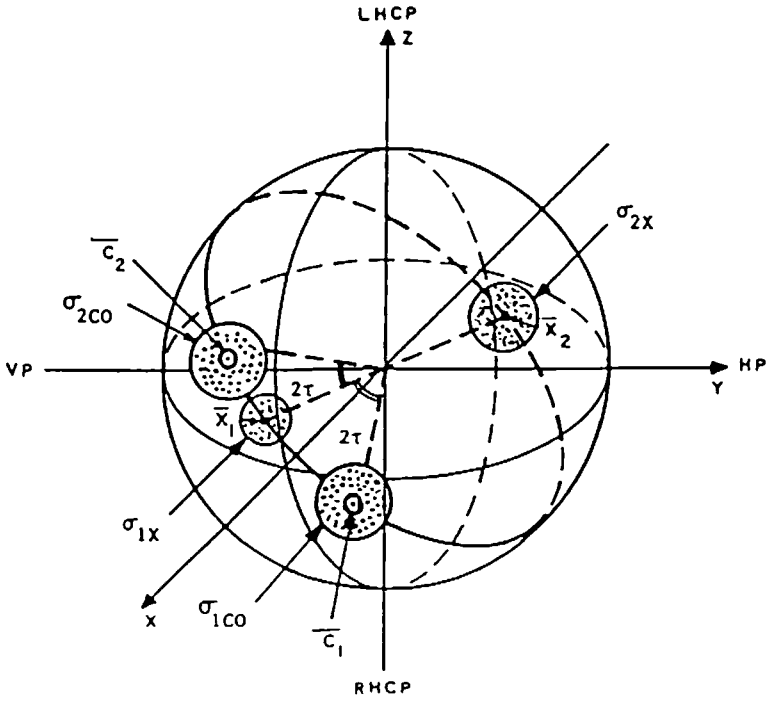

Fig. 1: Theoretical Representation of Optimal Polarization on The Poincare Sphere