CORRESPONDENCE BETWEEN GEOMETRIC PROPERTIES OF REAL OBJECTS AND THE HUYNEN PARAMETERS

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Abstract

This paper presents an approach to classify real objects, using polarimetric radar data, on the basis of the Huynen parameters (HUYNEN, 1970). For this purpose a computer program was developed to calculate and display the Huynen parameters from the polarimetric scattering matrix **S**, which is measured over a wide frequency range. It is demonstrated here that the Huynen theory is correct and applicable to electromagnetic inverse scattering problems to derive target classification operators.

Keywords: Huynen parameter, scattering matrix, inverse problem, object identification.

Introduction

A target in electromagnetic scattering problems is often described by its 'polarization properties'. Almost all practical targets produce different voltage (power) at the receiver of radar system, when illuminated by an electromagnetic wave of linear horizontal (h) or vertical (v) polarization. This is due to the vector nature of the interaction of the electromagnetic wave and the three-dimensional target structure.

It is well known (HUYNEN, 1965, KOSTINSKI–BOERNER, 1986) that two different ways can be used for the representation of the scattering properties of a target. Scattered voltage (electric field strength) or power can be measured. The target return is different for the various polarization combinations of the illuminating and receiving antenna.

The received voltage in an orthogonal horizontal-vertical measurement system is given by

$$V = \mathbf{S}\ \mathbf{a}\ \mathbf{b}\,, \tag{1}$$

where

S: complex scattering matrix, which describes the relation between incident and scattered electric field vectors with vertical and horizontal components as shown in (2),

a, **b**: polarization vectors of the transmitted and received electromagnetic fields.

$$\begin{bmatrix} E_h^s \\ E_v^s \end{bmatrix} = \mathbf{S} \begin{bmatrix} E_h^i \\ E_v^i \end{bmatrix} . \tag{2}$$

A more convenient way to describe a polarization state in terms of power are the Stokes vectors, instead of using the polarization vectors. In this case the received power is given in the following form:

$$P = M\mathbf{g}(\mathbf{a})\mathbf{h}(\mathbf{b}) , \tag{3}$$

where $\mathbf{g}(\mathbf{a})$ and $\mathbf{h}(\mathbf{b})$ are the Stokes vectors of the polarization states **a** and **b** as directly derived from the polarization vector (ULABY–ELACHY, 1990). **M** is the 4×4 real-value Stokes matrix, which represents the target in terms of power measurement.

The elements A_0, B_0, B, C, D, E, F, G and H in the Stokes matrix as given by (4) are called the Huynen parameters:

$$\mathbf{M} = \begin{bmatrix} A_0 + B_0 & F & C & H \\ F & A_0 + B_0 & G & D \\ C & G & A_0 + B & E \\ H & D & E & A_0 - B \end{bmatrix} . \tag{4}$$

The Physical Meaning of the Huynen Parameters

Each Huynen parameter has a geometric meaning based upon the decomposition of radar objects (HUYNEN, 1970, 1988a, 1988b).

A general radar target may be viewed as consisting of a part which is symmetric and a part which is non-symmetric, with coupling terms between them. Both parts of the target are determined by some Huynen parameters. A symmetric radar target is defined as an object which, when observed by a radar, has a plane of mirror symmetry going through the line of sight direction. For example, a cube has many planes of symmetry, but radar symmetry is obtained only, if this plane contains the radar observation axis, which is the line of sight.

A_0 is the most important parameter, the generator of target symmetry. If $A_0 = 0$ the target is purely non-symmetric.

$B_0 - B$ is called the generator of target non-symmetry. If $B_0 - B = 0$ we have a symmetric target.

B_0+B is the generator of target irregularity. If $B_0+B=0$ the target is regular. A general radar target is called regular when $\mathbf{S}_{11}$ and $\mathbf{S}_{22}$ of $\mathbf{S}$ are equal in magnitude and phase. E. g. a sphere is a purely symmetric and regular target. On the contrary, a corner reflector is non-symmetric and irregular. A long thin cylinder is symmetric but irregular.

C is a measure of the global shapes for predominantly symmetric targets. For a sphere $C=0$, while targets rendering high C values are long symmetric line targets.

D is a measure of local shape and it is related to the local radii of curvature of the specular point on the surface (BOERNER–FOO–EOM, 1987), i. e. $D=0$ if the local radii at the specular point are equal, but $D\neq 0$ if they differ from each other. In general D is small for man-made objects, but it can be large for cylindrical objects.

E is the torsion parameter. It is usually small for man- made objects. The parameter E is analogous to the parameter D except that E is the most sensitive in a circular basis system.

F is the target helicity parameter. It is analogous to the parameter C but in a circular basis system.

G and H are called coupling parameters. H is a measure of coupling due to the target orientation ϕ. If $\phi=0°$ then $H=0$, whereas G couples the symmetric and non-symmetric parts of the target; if $G=0$ (with $\phi=0°$) then either the target is purely symmetric or non-symmetric.

The relation of the different Huynen parameters can be illustrated by the graph of *Fig. 1.*

To compare objects of different size and orientation two transformation procedures can be applied to the Huynen parameters, these are desizing and desying.

Desizing means normalizing the Stokes matrix with the total power reflected by the target, which is $2(A_0+B_0)$. Desying is done by eliminating the orientation angle ϕ. This means that objects with different orientation about the line of sight direction are brought into the normal position ($\phi=0$).

Results

More than 100 objects were measured by the wide-band polarimetric radar measurement set-up of IHE (RIEGGER-WIESBECK, 1989). The analysis of these data resulted in the following conclusions concerning object identification:

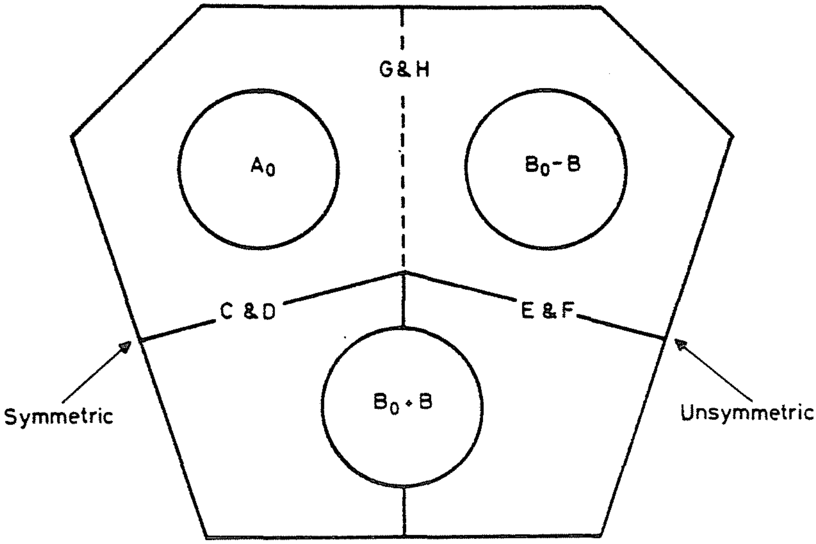

Fig. 1. Relation of the Huynen parameters

Single Objects

Table 1 has been composed of measurements of simple targets, summarizing the significance of the various Huynen parameters for the different groups of single objects. In the table BOP and BOM denote B_0+B and B_0-B, respectively. For comparison a wire-like target, featuring a diameter in the range of a few millimeters, and a cylinder, having a diameter of several centimeters were included among the measured objects. It should be noted that the wavelength of the wide-band measurement covered the range between 10 cm and 1.5 mm. This table is very helpful for the identification and classification of unknown objects.

Figs. 2 and *3* show the measured frequency-domain Huynen parameters. Although in *Fig. 2* (sphere) all five parameters are represented, only A_0 and C have significant non-zero values. For the thin wire, as it is shown in *Fig. 3,* three of the parameters are significant.

Complex Objects

To demonstrate the usefulness of the results given above, complex objects, consisting of several single scatterers, were measured. First, the resulting data were analyzed in the frequency-domain. Unfortunately it was not

Table 1

	Sphere	Cube	Wire	Corner reflector	Cylinder	Helix	Huynen parameters
AO	+++	+++	2A0=C=B0P	0	+++	0	symmetry
BOP	0	0	2A0=C=B0P	+++	+(+)	+++	irregularity
BOM	0	0	0	0	0	+++	unsymmetry
C	0	0	2A0=C=B0P	0	+(+)	0	global shape
D	0	0	0	0	++	0	local shape
E	0	0	0	0	0	0	torsion
F	0	0	0	0	0	+++	helicity
G	0	0	0	0	0	0	coupling
H	0	0	0	0	0	0	coupling

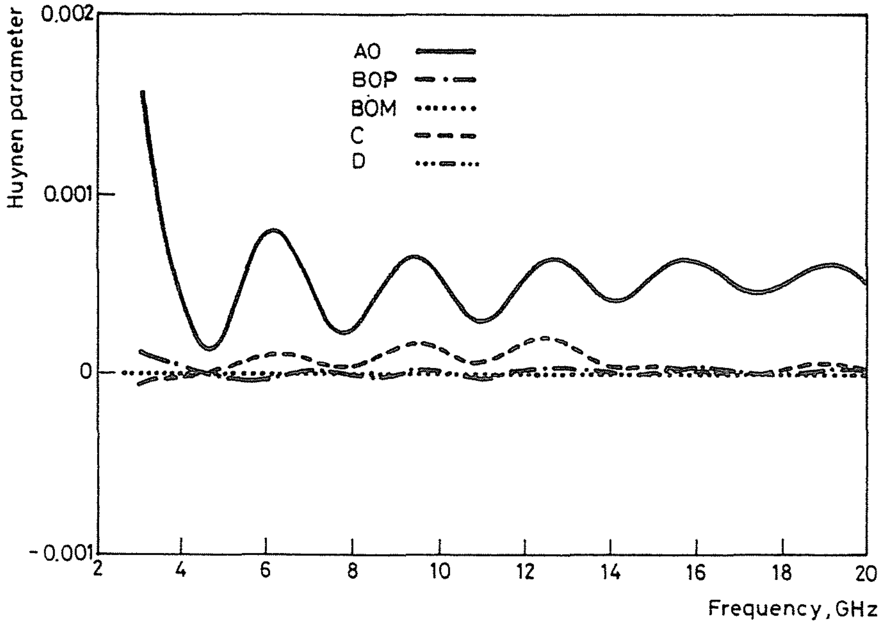

Fig. 2. Huynen Parameters for a sphere

possible to make definite statements on common properties of the complex objects over the applied frequency range, as superposition of the properties shown by the Huynen parameters.

A much better result was achieved by transforming the measured frequency domain wideband (3–20 GHz) data into the time-domain by ap-

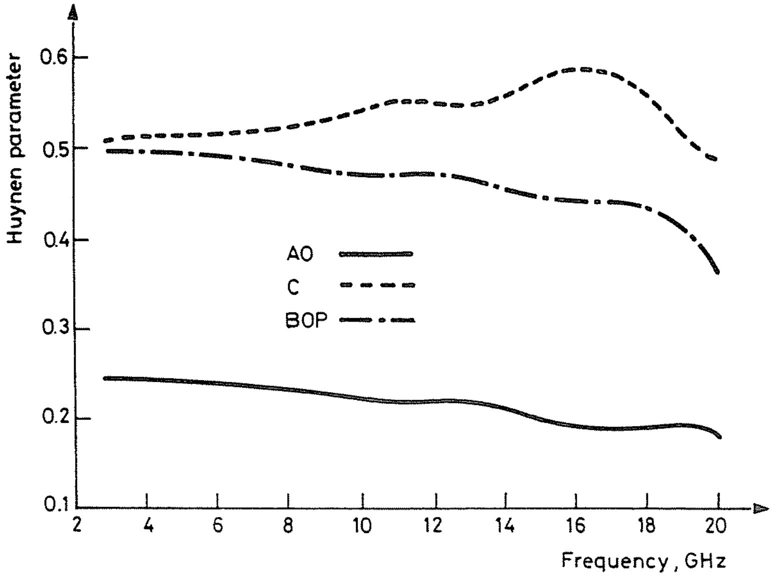

Fig. 3. Huynen Parameters for a wire-target

plying FFT. From the time dependent scattering matrix elements, the time dependent Huynen parameters can be calculated, which means range dependence simultaneously. This gives the possibility to analyze the geometric properties of complex targets along the radar line of sight.

Fig. 4 shows an example of Huynen parameters for a composed target. As the figure illustrates the position and aspect angle of the five targets this information can be extracted from the measurement. By interpreting the measured Huynen parameters, it becomes apparent that the observed target has the properties of a sphere at the front, 15 cm further it changes to that of a vertical dipol, and 10 cm further on it has the properties of a corner reflector. The different scattering centers can easily be separated in the time-domain.

The latter method could also be used in practice, quite easily. More details of this way of target analysis and explanations of these results can be found in (WIRTH, 1990).

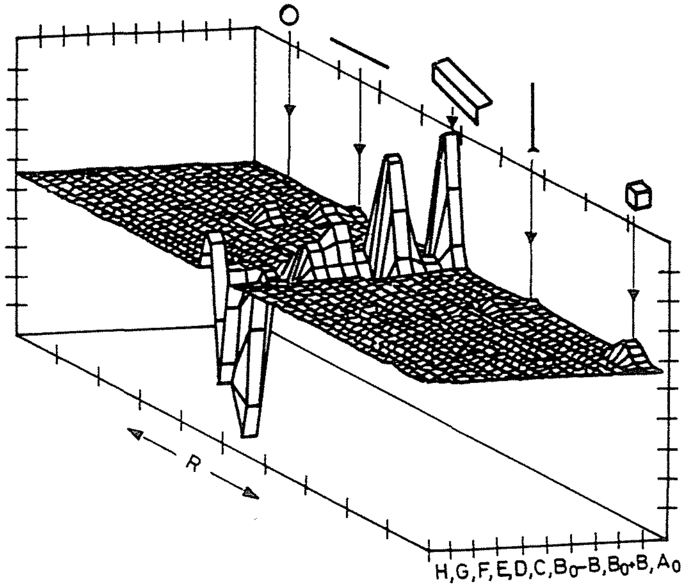

Fig. 4. Time-domain Huynen Parameters of a complex target

Summary

With the help of a Fortran program extensive investigation was conducted, which made it possible to classify different objects into definite groups. The selection of group- specific and significant parameters was made by way of several object measurements. The analysis of simple objects is viable in the frequency-domain, but on the other hand wideband measurement data transformed into time-domain are more suitable for analyzing complex targets.

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