ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 1, January 2014

Analysis of RCS Calculation Using a Novel Technique Based On Polarization Properties

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Abstract: The main aim of this paper is to characterization of targets using polarization properties of a target. Radar Cross Section is used to measure the characteristics of the targets. The response of the radar target is profoundly influenced by the operating frequency, the target orientation relative to the radar system, and the radar waveform and processing. RCS as a scalar number which is a function of Polarization of incident and received waves. The measurement of the polarization is called polarimetry. In-depth study of radar cross section in terms of transmitted and received polarizations in an attempt to better understand the potential of polarimetric radar. In order to know the characteristics of the target it is very essential to know the polarization properties of that particular target which depends upon scattering nature of the target. Polarization properties of a target can be obtained using polarization scattering matrix (PSM). The polarization scattering matrix, is a generalization of the concept of radar cross section, and includes amplitude, phase, and polarization. In this paper the polarization matrix of various geometrical shapes can be derived. For radar target recognition (RTR), a method using properties of the polarization scattering matrix (PPSM) can be developed. A sphere and dipole have been considered to calculate the polarization matrix and polarization properties. The determinant, Trace of Power, Depolation and Eigen polarization angle are analyzed.

Keywords: RCS, polarimetric, polarization, trace of power, depolation, eigen polarization angle

I. INTRODUCTION

The word RADAR is an acronym for the words Radio Detection and Ranging, i.e. finding and positioning a target and determining the distance (range) between the target and the radar by using radio frequency. The basic principle behind the radar is simple: transmitter sends out a very short duration pulse at a high power level. The pulse strikes an object (or a target) and energy will be reflected (known as radar returns or echoes) back to the radar receiver. Radar determines the distance (range) to the target by measuring the travel time of the radar pulse to get the target and to come back and then divides that time in two. For extracting the target information from the echo, the signal must be of sufficient magnitude [1]. The radar equation is used to predict the echo power to assist in making the determination of whether or not above mentioned condition is met. These echoes are then processed by the radar receiver to extract target information such as range, velocity, angular position, and other target identifying characteristics. Radar can perform its function at long or short distances and it can operate in darkness, haze, fog, rain, and snow. Its ability to measure distance with high accuracy and in all weather conditions is one of its most important attributes [2].

II. RADAR CROSS SECTION

Now a day's characterization of targets using radar is very important in Air Traffic Control, Defense, and Stealth etc. Radar Cross Section is used to measure the characteristics of the targets. The response of the radar target is profoundly influenced by the operating frequency, the target orientation relative to the radar system, and the radar waveform and processing. RCS as a scalar number which is a function of Polarization of incident and received waves. A more complete description of the interaction of the incident wave and target is given by polarization scattering matrix. Both linear and circular polarizations are of interest, and also, a combination of the two, wherein circular polarization is transmitted, while a two-channel receiver measures orthogonal linear polarization components. The measurement of the polarization is called polarimetry[9,12,13,14,18].

III. RADAR POLARIMETRY

Radar Polarimetry is the science of acquiring, processing and analyzing the polarization state of an electromagnetic field. In-depth study of radar cross section in terms of transmitted and received polarizations in an attempt to better understand the potential of polarimetric radar. The basis for this analysis is the polarization scattering matrix. The polarization scattering matrix, is a generalization of the concept of radar cross section, and includes amplitude, phase, and polarization. The measurement of the elements of the polarization scattering matrix is discussed in this paper. In this paper the polarization scattering matrices (both for linear and circular polarizations), are derived for the simple targets the sphere and dipole. It is known that polarization

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 1, January 2014

properties depend on the object's shape, size, and composition, and upon the radar characteristics [6].

IV. RCS CALCULATION USING POLARIZATION PROPERTY

The full polarization radar can receive all the electromagnetic backward wave of targets, while the mono-polarization cannot. For a given set of radar characteristics, the scattering matrix of a target permits prediction of radar return for any polarization. One example for RTR is that the ball which can be the same RCS as a cone object is not identified while the polarization radar can be easily discovered, because the scattering matrix of ball at any azimuth angles and pitch angles is the same, while the scattering matrix of a cone target varied with azimuth angles and pitch angles. In this paper the polarization matrix of various geometrical shapes are derived. For characterizing the radar target recognition, a method using properties of the polarization scattering matrix is presented. The properties of the polarization scattering matrix: determinant, Trace of Power Scattering Matrix, Depolation, Eigen polarization angle and Module of Polarization Ellipticity are analyzed. These properties are analyzed for different orientation angles of the targets in this paper [3,4, 5, 8, 10, 11]

A. Formulation and Analysis of proposed technique

Polarization is implicit in this definition of radar cross section, and usually, it is assumed that a single polarization is employed for both the transmitted and received fields. This assumption is not required, however, and radar cross sections can be defined for arbitrary polarization of transmitted and received fields. An arbitrarily polarized plane wave can be expressed as the sum of two plane waves having orthogonal, but otherwise general polarizations. Following in phasor notation, the transmitted field can be expressed as [15, 16, 17].

$$\overline{E}^T = \overline{E}_1^T + \overline{E}_2^T$$

The received fields are

$$E_1^R = a_{11}E_1^T + a_{12}E_2^T$$
$$E_2^R = a_{21}E_1^T + a_{22}E_2^T$$

The matrix [S] , given by

$$[S] = \begin{bmatrix} |a_{11}|e^{j\phi_{11}} & |a_{12}|e^{j\phi_{12}} \\ |a_{21}|e^{j\phi_{21}} & |a_{22}|e^{j\phi_{22}} \end{bmatrix}$$

For the monostatic radar case, $\phi_{12}=\phi_{21}$ and $|a_{12}| = |a_{21}|$

$$[s]_M = e^{j\varphi_{12}} \begin{bmatrix} |a_{11}|e^{j(\varphi_{11}-\varphi_{12})} & |a_{12}| \\ |a_{12}| & |a_{22}|e^{j(\varphi_{22}-\varphi_{12})} \end{bmatrix}$$

circular polarization

$$[s_C]_M = e^{j\varphi_{RL}} \begin{bmatrix} |a_{RR}|e^{j(\varphi_{RR}-\varphi_{LR})} & |a_{LR}| \\ |a_{RL}| & |a_{LL}|e^{j(\varphi_{LL}-\varphi_{RL})} \end{bmatrix}$$

linear polarization

$$[s_L]_M = e^{j\varphi_{HV}} \begin{bmatrix} |a_{HH}|e^{j(\varphi_{HH}-\varphi_{VH})} & |a_{VH}| \\ |a_{HV}| & |a_{VV}|e^{j(\varphi_{VV}-\varphi_{HV})} \end{bmatrix}$$

Relation between circular and linear polarization

$$e^{i(\phi_{RL}-\phi_{HV})}[s_C]_m = [R_{LC}][s_L]_m[T_{LC}]^{-1}$$

Scattering matrix

$$[s]_M = e^{j\varphi_{12}} \begin{bmatrix} \left(\dfrac{E^R{}_{11}}{|E^T{}_1|}\cdot\dfrac{|E^R{}_{21}|}{E^R{}_{21}}\right) & \left(\dfrac{|E^R{}_{12}|}{|E^T{}_2|}\right) = \left(\dfrac{|E^R{}_{21}|}{|E^T{}_1|}\right) \\ \left(\dfrac{|E^R{}_{12}|}{|E^T{}_2|}\right) = \left(\dfrac{|E^R{}_{21}|}{|E^T{}_1|}\right) & \left(\dfrac{E^R{}_{22}}{|E^T{}_2|}\cdot\dfrac{|E^R{}_{12}|}{E^R{}_{12}}\right) \end{bmatrix}$$

Let us further suppose that there are two permissible polarization states denoted by (1,2), with the two polarization states being orthogonal. In general then, i and j can take on any combination of values denoted by i,j = 1,2. σ_{ij} is the cross section of the target for the case of received polarization of state"i" and transmitted polarization of state "j".

$$\sigma_{ij} = 4\pi R^2 \left[\frac{\left(\dfrac{P_{ri}}{A}\right)}{\left(\dfrac{P_{tj}G}{4\pi R^2}\right)} \right]$$

The quanity (P_{ri}/A) is the power density (power per unit area), or the intensity, of reflected signal at the radar, and the quanity $\dfrac{P_{tj}G}{4\pi R^2}$ is the intensity of the radar signal incident on the target.

Although not quite as straight forward, the above procedure can be to determine $|E_{ij}^R|$ and $|E_j^T|$ for the case of a monostatic radar operating in a homogenous, lossy medium. The results are expressible as

$$|E_{ij}{}^R| = a\left(\frac{P_{ri}}{A}e^{-2\alpha R}\right)^{\frac{1}{2}} \qquad (3)$$

and

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 1, January 2014

$$\left|E_j^{\ T}\right| = a\left(\frac{P_{tj}G}{4\pi R^2}e^{-2\alpha R}\right)^{\frac{1}{2}}$$

Where α represents the attenuation coefficient of the medium.

We wish to emphasize that $\left|E_{ij}^{R}\right|$ and $\left|E_{j}^{T}\right|$ are not direct radar measures, but they can be related to measures of received and transmitted power. In addition, by determining the phases of the radar signals, the phases of E_{ij}^{R} and E_{j}^{T} can also be determined. Thus, when we refer to received and transmitted fields we are, strictly speaking, referring to E_{ij}^{R} and E_{j}^{T}.[7]

B. Properties of the polarization scattering matrix

In the *H-V* basis, the relationship between the incident and reflected fields may be expressed as

$$E_S = [S]E_i$$

where E_s is the reflected field, E_i is the incident field, the fields are related by the Sinclair matrix [*S*]

$$S = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}$$

For mutually object: $S_{HV} \approx S_{VH}$

Then the IPPSMs are obtained

1) *Determinant* $|\Delta|$

$$|\Delta| = |\det[S]| = \left|S_{HH}S_{VV} - S^2{}_{HV}\right|$$

2) *Trace of Power Scattering Matrix* P_1

$$P_1 = |S_{HH}|^2 + |S_{HH}|^2 + 2|S_{HV}|^2$$

3) *Depolation D*

$$D = 1 - \frac{|S_{HH} + S_{VV}|^2}{2P_1}$$

4) *Eigen- polarization angle* φ_0

$$\varphi_0 = \frac{1}{2}\arctan\frac{2\,\mathrm{Re}(S_1 * S_{12})}{\mathrm{Re}(S_1 * S_2)}$$

where.* denotes complex conjugation,

$$\begin{cases} S_1 = S_{HH} + S_{VV} \\ S_2 = S_{HH} - S_{VV} \end{cases}$$

5) *Eigen- polaization Ellipticity* τ_0

$$\tau_0 = \frac{1}{2}\arctan\frac{j2S_{12}^*}{S_1}$$

where

$$S_{12}^* = S_{12}\cos(2\varphi_0) - \frac{1}{2}S_2\sin(2\varphi_0)$$

TABLE I
PHYSICAL CHARACTERISTICS OF PPSM

PPSMs	Physical characters
$\|\Delta\|$	It means 'fat' or 'thin' of target
P_1	It means 'small' or 'big' of target
D	It means the number of scattering centers, while 0<D<0.5 as to one scattering center, 0.5<D<1 as to two or more scattering centers
φ_0	It measures the relative orientation between the antenna and the axis of the eigen-polarization ellipse
τ_0	It relates to the symmetry of the target

The physical characteristics of PPSM are presented in the table-I

V. APPLICATIONS

A. Properties of the polarization scattering matrix

Let us consider a large sphere at normal incidence made of any material. The target matrix of a sphere is always unit matrix if its magnitude is normalized to 1.

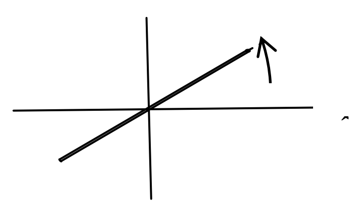
$$[S]_{sphere} = \begin{bmatrix} \sqrt{\pi R^2} & 0 \\ 0 & \sqrt{\pi R^2} \end{bmatrix}$$

where R = radius of the sphere

B. Dipole

Assume that a thin wire (diameter << wavelength) or a sharp edge of a conducting body is constrained to lie (14) to the $\hat{x}, \hat{y}$ plane and at an angle γ with respec $\hat{x}, \hat{z}$ plane . The dipole scattering matrix for linear representation of polarization is given by

$$[S_L]_{dipole} = \begin{bmatrix} \cos^2\gamma & \sin\gamma\ c \\ \sin\gamma\cos\gamma & \sin^2 \end{bmatrix} \quad (15)$$



(16)

(17)

Fig.1. Dipole parallel to $\hat{x}$ and $\hat{y}$

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
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The dipole scattering matrix for circular representation of polarization is given by

$$[S_C]_{dipole} = \begin{bmatrix} e^{-j2\gamma} & 1 \\ 1 & e^{j2\gamma} \end{bmatrix}$$

VI. RESULTS AND DISCUSSIONS

Sphere Polarization Properties for linear polarization

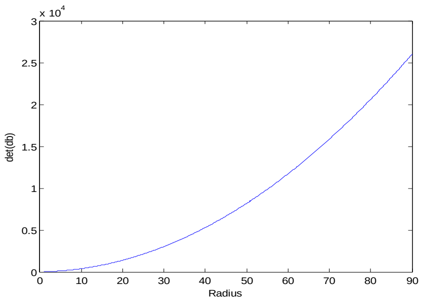

Fig 2.Variation of determinant with radius

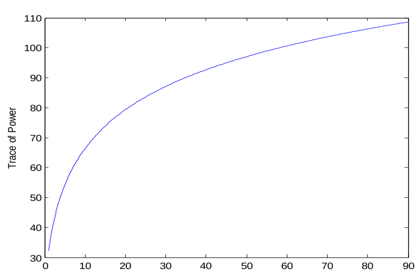

Fig 3. Variation of trace of power with radius

The determinant and trace of power are shown in figures (2 and 3). The determinant and trace of power are constant for a sphere at different orientation angles as the shape of the sphere remains unchanged from any direction and it is always symmetric at any orientation angle. The determinant and trace of power are determined for spheres with different radii.

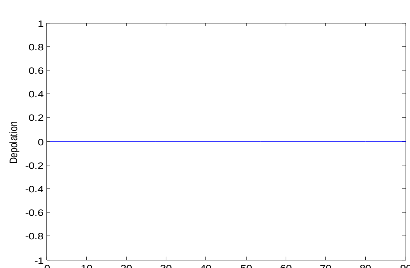

Figure 4. Depolation for sphere with different radii

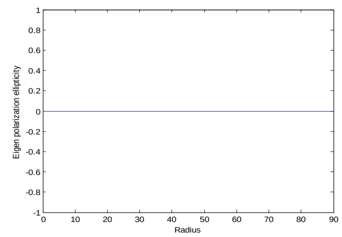

Figure 5. Variation of Eigen polarization Ellipticity for sphere with different radii

From above Fig 5. the value of depolation is 0 for any size of sphere. With this one can say that the scattering centre for a sphere is one. Fig 6. shows Variation of Eigen polarization Ellipticity for sphere with different radii. It is observed that the Eigen polarization Ellipticity is zero for sphere of any size. This is because by changing the orientation of the sphere its shape cannot be changed.

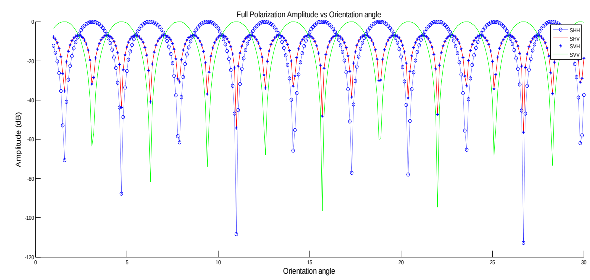

Figure 6. Full polarization amplitudes of a dipole

Figure 6. shows the full polarization amplitude of a dipole. From this figure we can say that amplitude difference of 45dB for co-polarization and amplitudes of cross polarizations are equal

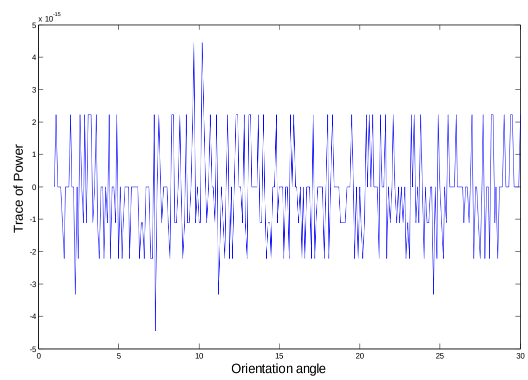

Figure 7. Variation of trace power P_1 with orientation angle Ellipticity with orientation angle.

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 1, January 2014

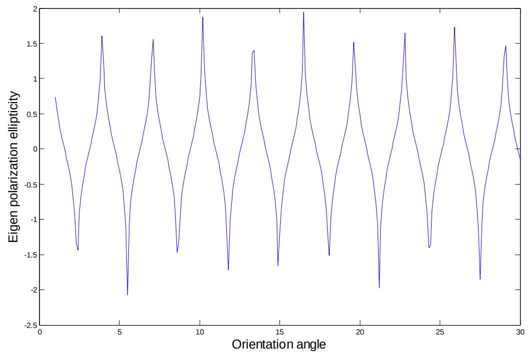

Figure 8.Variation of Eigen polarization

The determinant and trace of power scattering matrix P_1 are invariant with orientation varied in 0^0 to 30^0. The eigen polarization angle varies from -44^0 to 44^0. The eigen polarization ellipticity varies from -2 to 2 symmetrically and regularly for dipole.

VII. CONCLUSION

We obained polarization properties of a sphere and dipole using polarization scattering matrix (PSM). The determinant, Trace of Power Scattering Matrix, Depolarization, Eigen polarization angle and Module of Polarization Ellipticity are determined which helps in identifying the different objects which are having same radar cross section (RCS). For sphere depolarization value is zero which indicates that the symmetric scattering centre for a sphere is one and determinant, Trace of Power Scattering Matrix, Depolation, and Module of Polarization Ellipticity are constant because the shape of the sphere remains unchanged at any orientation angle. For dipole it is observed that the amplitudes of cross-polarization are equal and the amplitude difference of co-polarization is about 45dB. The determinant and trace of power scattering matrix P_1 are invariant with orientation varied in 0^0 to 30^0. The value of depolation observed is 0.5 which indicates that the scattering centre for a dipole is one. The eigen polarization angle varies from -44^0 to 44^0 and the eigen polarization ellipticity varies from -2 to 2 symmetrically and regularly for dipole. This is indicates that the dipole is cylindrically symmetrical.

ACKNOWLEDGMENT

The Authors would like to acknowledge the support from Sri Kalidindi Raghu, Chairman, Raghu Educational Society and P.S.RChowdary, HOD, Department of ECE, RIT.

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