A MODEL OF MEDIUM DEPOLARISATION EFFECTS ON POLARISATION VECTOR POSITION

Jozef Hanuska and Jiří Moc,
Member, IEEE
Radar Department
Air Force and Air Defence Faculty
Military Academy in Brno
Kounicova 65, 612 00 Brno
Czech Republic

Abstract

The paper presents the results of modelling the influence of real atmosphere with precipitation clouds on the radar signal polarisation status. The relationship between the signal vector depolarisation shift value and the initial wave polarisation is examined.

Keywords:
Electromagnetic wave propagation, depolarisation in atmosphere, polarisation vector, passive radar

1. Introduction

One of the problems associated with the reception and measurement of the signal characteristics by a passive radar is the evaluation of atmospheric effects on the incoming wave polarisation. The outcomes of the theoretical research and experiments in the field of communications (e.g. [1], [2]) and radar systems [3] prove a significant conclusion: a depolarisation of the electromagnetic wave occurs practically whenever hydrometeorological formations are present in the atmosphere. Analytical and numerical relationships between differential attenuation, differential phase shift, crosspolarisation parameters and signal wavelength at various precipitation intensities are outcomes of the research. However, for purposes of the radar signal polarisation selection and the radar transmitter classification according to their polarisation, it is necessary to know how the wave polarisation status changes as a consequence of passing through the medium in terms of the polarisation status shift on the Poincaré sphere. It is a prerequisite to the polarimetric radar receiver parameter determination. There is no satisfactory answer to this question in the available literature. That is why it was necessary to proceed to the solution of the task how to determine the possible values of the signal vector shift on the Poincaré sphere due to passing through the atmosphere with meteorological formations. A computer modelling method was used for the quantitative evaluation of the real medium influence on the signal polarisation status.

2. A Model of Spread Medium

Meteorological phenomena are complex and dynamic in time and space and it is not easy to express all relations by means of simple relationships. To approximate the real status as much as possible, a model of the environment with meteorological formations and its influence on the radar signal polarisation was designed.

The model is based on a substitution of the real distribution of hydrometeors by a set of rectangles representing clouds with a constant precipitation intensity. One cloud is defined by five parameters four coordinates of the cloud corner point and its rain intensity. The numerical values of the meteorogical formations depolarisation effects were taken from [4]. As far as the precipitation phenomenon dimensions and space distribution are concerned, the essential data from [5] are utilized. An area of 200x400km was chosen for the model. It corresponds to the work area of a common passive radar. This area is described by a cartesian coordinate system with a passive radar at the point (100, 0)km.

A considerable number of situations with various meteorological formation distribution were modelled to find the real medium influence on the signal polarisation vector. Depolarisation effect for main radar bands (bands D, E/F, G/H, I and J) in nine transmitter locations was investigated. The transmitter locations cover the whole area considered. Eight different positions of the transmitted signal polarisation vector were taken into account.

The model simulates the effect of a meteorological situation on the polarisation status of the received signal according to input variables, i. e. signal source location and precipitation clouds distribution. The solution is defined by the following steps:

- determination of an equation for the line passing through the emitter and the passive receiving site
- determination of the number and coordinates of the points of intersections of the straight line thus obtained with the lines representing individual cloud borders

- determination of the length of abscissae representing the radar signal path in individual precipitation clouds
- determination of the extent of the individual meteorological formation influence on radar signal and the final position of the signal polarisation vector depending on differential attenuation, differential phase shift and crosspolarisation isolation values for a given frequency and precipitation intensity.

The computation algorithm was implemented in the programming language C as one part of a more complex project of the passive radar signal processing.

3. Results of Modelling

As the extent of the results obtained is too large, only the results for one of the meteorological situations, three spatial positions of the emitter and three signal polarisations are presented for illustration.

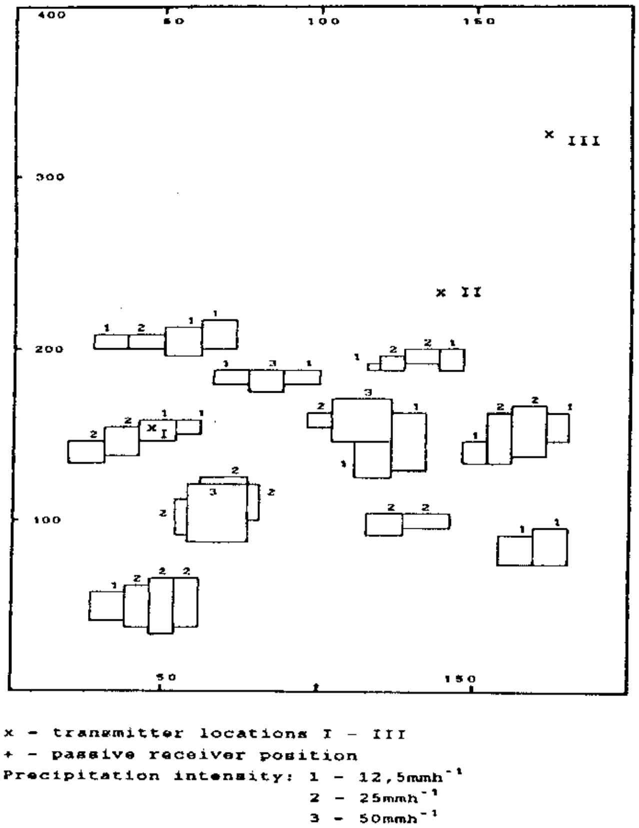

Fig. 1.
Spatial distribution of precipitation clouds and signal sources

Fig. 1 shows the distribution of precipitation clouds, which is typical for the region of Central Europe, after substitution by a model consisting of rectangular elements with a constant rain intensity. Three spatial positions of the transmitter in Fig. 1 are indicated by a symbol and a number. The initial polarisations of the transmitted wave are: linear horizontal $(2\varphi = 0^o, 2\tau = 0^o)$, left-handed circular $(2\varphi = -, 2\tau = 90^o)$ and general elliptical ($2\varphi = 34^o, 2\tau = 43^o$, which corresponds to the horizontal-to-vertical component ratio 2:1 and phase shift 45^o between both components).

The signal vector depolarisation shift values for individual frequency bands are summarized in Tab. 1, where data for three radar transmitter locations and three initial signal polarisations are given.

Fig. 2 shows data for J band in the form of a polarisation chart. For precipitation situation according to Fig. 1 and incidental radar transmitter position, the probability of exceeding the given value of depolarisation shift on the Poincaré sphere was investigated. The probability distribution for circularly polarized signal is presented in Fig. 3.

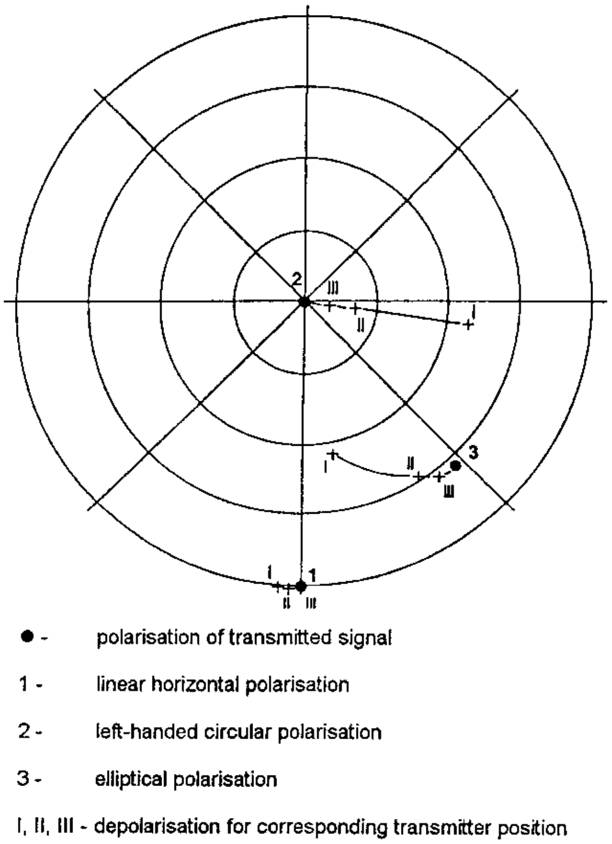

Fig. 2.
Depolarisation shift for J band in polarisation chart

4. Dependence of Polarisation Vector Shift on Initial Signal Polarisation

The dependence of the signal polarisation status change on the initial polarisation vector position on the Poincaré sphere is an important fact when determining the medium depolarisation effect. This dependence was investigated for individual radar frequency bands and various rain

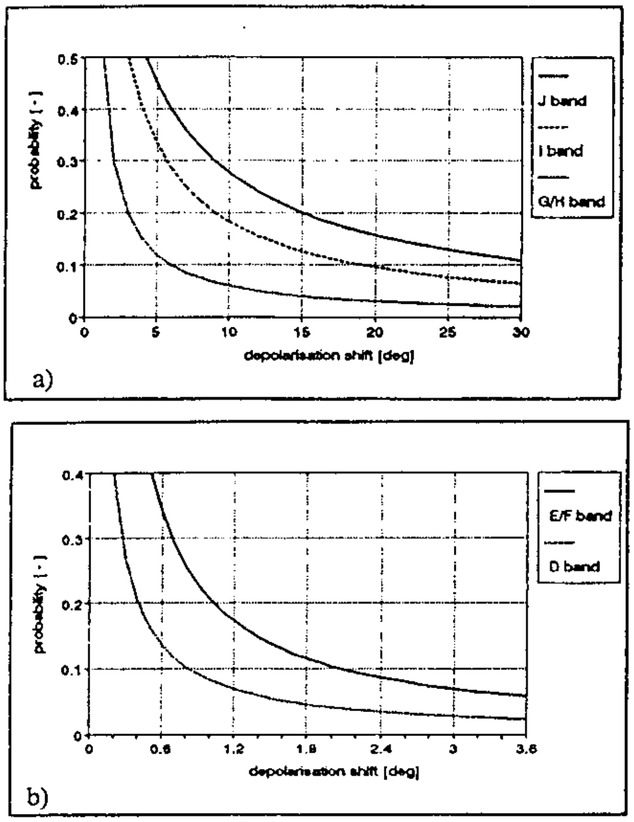

Fig. 3.
Probability of exceeding the given value of depolarisation shift
a) J, I and G/H bands
b) E/F and D bands

intensities by means of a model when signal passes through a 10km trajectory in a cloud of a constant precipitation intensity for various initial vector polarisations. The final graph of the signal polarisation status shift value dependence on the transmitted signal polarisation distance from the point representing linear horizontal polarisation is shown in Fig. 4. It corresponds to the movement of the polarisation vector of the transmitted signal from the equator to the pole of the Poincaré sphere. The results show that the depolarisation shift values for a 10km path length and for a precipitation intensity of $25 mmh^{-1}$ range, depending on the wavelength, up to $1°$ for horizontally polarized wave and up to $5°$ for circularly polarized wave. When the transmitted signal polarisation status moves along the main circle of the Poincaré sphere through the points representing circular polarisations and slant linear polarisation with a slope of $45°$, which corresponds to changes in the phase shift between the signal components while their amplitude ratio is constant, the polarisation shift value remains constant.

5. Conclusion

The paper briefly summarizes the essential results of modelling the atmospheric depolarisation effect on radar signals through the values of polarisation vector shift on the Poincaré sphere. The extent of the depolarisation effects of real medium, expressed in terms of polarisation status shift on Poincaré sphere is a value depending on many factors, the most important of which are wavelength, initial polarisation of the transmitted signal, signal trajectory length and configuration, and the immediate status of the meteorological conditions. The obtained numerical values correspond to the outcomes of experiments in [6]. However, in this article only one final signal parameter - the polarisation ellipse tilt angle - was investigated. In addition, the paper demonstrates the depolarisation shift magnitude dependence on the initial transmitted signal polarisation.

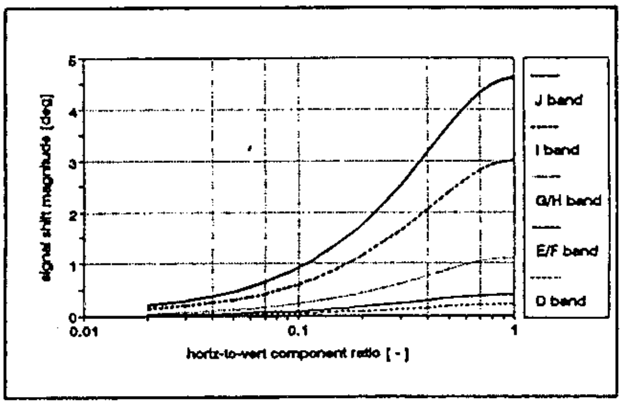

Fig. 4.
Dependence of depolarisation shift on amplitude ratio of both signal components

Polarisation type	Transmitter location	Depolarisation shift [deg] for radar band				
		D	*E/F*	*G/H*	*I*	*J*
HP	*I*	0.00	0.00	0.07	0.28	0.67
	II	0.00	0.00	0.00	0.03	0.08
	III	0.00	0.00	0.00	0.00	0.04
LHCP	*I*	2.06	3.98	10.31	23.85	36.55
	II	0.51	0.89	2.74	6.78	10.21
	III	0.21	0.41	1.13	3.07	4.71
EP	*I*	1.64	3.19	8.26	19.11	29.75
	II	0.41	0.71	2.19	5.41	8.17
	III	0.17	0.33	0.90	2.46	3.77

Tab. 1.
Values of depolarisation shift on the Poincaré sphere

6. Reference

[1] ARNOLD,H.W.- COX,D.C.- HOFFMAN,H.H.- LECK,R.P.: Characteristics of rain and ice depolarisation for a 19- and 28-GHz propagation path from a Comstar satellite. IEEE Transactions on Antennas&Propagation, vol. AP-28, 1980, January, str. 22-28.

[2] KHARADLY,M.M.Z.- CHOI,A.S.-V.: A simplified approach to the evaluation of EMW propagation characteristics in rain and melting snow. IEEE Transactions on Antennas& Propagation, vol. AP-36, 1988, February, str.282-196.

[3] BRINGI,N.V.: Polarimetric radar signatures of precipita- tion at S- and C-bands. IEE Proceedings, Pt.F, vol. 138, 1991, pp. 109-119.

[4] OGUCHI,T.: Electromagnetic wave propagation and scattering in rain and other hydrometeors. Proceedings of the IEEE, vol.71, 1983, September, pp.1029-1078.

[5] JESKE,H.E.G.: Atmospheric effects on radar target identification and imaging. Proceedings of the NATO Advanced Study Institute, D Reidel Publishing Company, Dodrecht, Holland, 1976.

[6] HENDRIX,C.E. - KULON,G. - RUSSEL,T.A.: Specification of polarisation parameters for optimal-performance in rain of dual circularly polarized radio links. IEEE Transactions on Antennas&Propagation, vol. AP-40, 1992, May, pp.510-515.

About authors,...

Jiří Moc was born in Pelhrimov [Czechoslovakia], in 1953. He received the M.E. degree in Radar Engineering from the Military Academy in Brno, in 1977 and Ph.D. degree in Radar and Navigation Engineering from the Military Academy in Brno, in 1982. He is currently the Head of the Radar Department and from February 1994 he is the Rector [President] of Military Academy in Brno. His research interests include Radar and EW systems, Antennas and Millimeter Wave Technology.

Jozef Hanuska was born in Zvolen [Czechoslovakia], in 1957. He received the M.E. degree in Radar Engineering from the Military Academy in Brno, in 1981. At present he is the Ph.D. student supervised by Assoc.Prof. Jiří Moc at Military Academy in Brno. He is interested in EW systems.