9th MICROWAVE CONFERENCE

MIKON-91

Rydzyna - Poland

May 20-24, 1991

Vol.1

Honorary Chairman of the Conference

Prof. Adam SMOLIŃSKI

Polish Academy of Science

Chairman of the Conference

doc. Jerzy FIETT

NON-LINEAR ADAPTIVE POLARIZATION FILTERING : A METHOD FOR REJECTING DISTRIBUTED GROUND CLUTTER

M. Gherardelli*, D. Giuli*, M. Fossi*, L. Facheris*

ABSTRACT

In this paper a novel non-linear polarization filter is described, which is derived from the non-linear Polarization Vector Translation (PVT) filter. Such a filter in conceived for adaptive cancellation of ground clutter. Its operation is based on scan-to-scan stationarity and asymmetric short-term changement of ground clutter polarization.

INTRODUCTION

When an electromagnetic wave is radiated by a fixed polarization radar transmitter, its polarization can be considered constant in time and the wave is said completely polarized.

Due to interaction with ground, targets and different obstacles, the polarization of the backscattered wave can vary thus becoming partially polarized. A measure of the polarization randomness is given by the polarization degree[1], which is the ratio between the power associated to the completely polarized component and the total power of the wave.

The utilization of the information contained within the polarization states of backscattered signals relative to the polarization state of the transmitted signal, as well as the utilization of information contained within the polarization states of interfering signals, is a subject of interest in radar research. Indeed recent studies have demonstrated that useful improvements in the ability to detect targets in the clear and in the presence of hostile environment can be obtained by applying signal processing in the polarization domain [2],[3],[4].

This requirement is satisfied when the radar receiver can operate upon vector signals: this needs two othogonally polarized receiving channels, which allow for collecting the whole power of the received wave and sensing its polarization as well. The vector signals can be first processed in time/frequency domain [2], over

*
Dipartimento di Ingegneria Elettronica
Via S. Marta, 3
50139 FIRENZE - ITALY

each channel, and then in the polarization domain by means of suitably designed filters.

To enhance radar target detection capability in the presence of ground clutter, we can resort to polarization filtering; this requires that the different polarization features of the interfering signals be optimally exploited. It is known that rapid changes of polarization from scan to scan are typical of aircraft target echoes, while presenting limited polarization changes during the same scan. Conversely the polarization behaviour of ground clutter appears more stationary from scan to scan. This behaviour is typical, at least, in low resolution radars using circularly polarized antenna [5].

Such a behaviour makes adaptive polarization filtering profitable for improving target detection in the presence of ground clutter: the high stationarity in space and time, and the high degree of polarization allow to estimate ground clutter parameters during one antenna scan and then to adapt the antenna polarization at the successive scans so that disturbance signals can be rejected.

This paper presents a device among those introduced above, which is derived from the non-linear PVT proposed by Poelman [6]. Such a device is able to process the input signal samples accounting for the asymmetric behaviour of ground clutter in the polarization domain, while changing itself during each scan. The filter, once the needed polarization parameters are estimated, processes the polarization of the received samples modifying their polarization so that an asymmetric filter response in the polarization domain is synthesized which matches the ground clutter behaviour. The disturbance cancellation results thus improved relative to the case of conventional polarization filters [3].

THE ADAPTIVE POLARIZATION FILTERING

Before introducing the novel filtering technique some polarization parameters must be defined for better understanding the device operation.

The vector signal present at the input of the receiver is constituted of two dimensional vector samples, which describe the echo polarization state of the wave backscattered by each resolution cell, at different ranges and/or different azimuth angles.

The polarization state of a radar signal sample can be represented onto the polarization chart. This is the projection of the Poincaré sphere onto its equatorial plane [7]. Each point of the graphic representation refers to generally elliptic polarisation with ellipticity angle τ and orientation angle ϕ : each point has polar co-ordinates given by ($\cos 2\tau$, 2ϕ). According to this representation linear polarisations lie on the external circumference (τ=0): the horizontal and vertical polarizations have ϕ=0 and $\phi=\pi$, respectively, and the circular polarizations lie on the centre ($\tau=\pm\pi/4$). Since polarization chart is ambiguous with respect to the polarisation sense, different symbols are usually used for representing left-hand and right-hand polarizations.

It is also useful to define the ellipticity ratio parameter as $r=tg(\tau)$, with $r \in [0,2\pi]$.

The device presented in this paper is able to reduce the power contribution of clutter by adapting antenna polarization on reception. It combines the two receiving signals by means of suitable complex weights, thus obtaining a Virtual Polarization Adaptation on reception. For estimating the weights, this device resorts to the following estimates: the average polarisation of the set of samples received during each scan, the preferred direction of changement of ground clutter polarisation state during dwell-time, and polarization spread around such a mean direction. This parameters can be used to describe the typical behaviour of ground clutter as observed during measurements [8].

In the case of distributed ground clutter the polarisation state of samples lines up along some preferred directions over the polarisation chart; in the case of point clutter phenomena, a quite clustered distribution of the polarisation state of the samples is instead observed during dwell-time. In both cases that polarization behaviour appears to be highly stationary from one scan to another.

The considered filter can modify (through a non-linear transformation) both the ellipticity ratio and the orientation angle of polarisation ellipse, i.e. the polarisation state, of each input sample. When resorting to the modification of the orientation angle alone, good suppression of point clutter phenomena is obtained; while when both the above parameters are independently changed, extended ground phenomena can optimally be attenuated. In the latter case the polarization state of input signals is modified asymmetrically with respect to the average polarization: the disturbance samples are thus placed optimally with respect to the suppression area of any type of non-adaptive polarization filter, such as a single notch filter, used as final stage of the proposed device.

In Fig. 1 constant attenuation contour lines are shown for the theoretic filter just described: it can suppress a clutter sample sequence as that suggested in figure (triangle signs around the preferred direction ϕ).

Fig. 2 shows the block diagram of the proposed filter. The input data sequence is transferred both to a buffer section and to a PVT transformation block. The buffer section collects the data set during one scan and gives the input to an estimation section which provides the filtering blocks with the needed values, for adaptation during the next scan: these parameters are the average polarisation, the leading

(average) orientation angle Γ of the preferred direction along which samples line up, the standard deviations s_Γ and s_τ which describe the dispersion of the polarization of the samples around the average value of the orientation polarisation angle, ϕ; and the ellipticity polarisation angle τ respectively.

Thus the estimation block provides the linear PVT [9] with the average polarisation of samples, while the other parameters are transfered to the non-linear PVT block.

The linear PVT transformation operator modifies the polarisation of the input data samples at the actual scan by translation of the related representative points over the polarisation chart. Specifically the average polarisation of data samples is adopted, so as to transform it into the left handed circular polarisation after through a polarization basis transformation: after such a transformation all samples appear located around the center point of the polarisation chart.

$$(E_i)_{NL} = M_{NL}\,(E_i)_{TL}$$

where the matrix M_{NL} is the non-linear PVT operator which processes the linear-PVT output samples. The MNL operator depends on $(E_i)_{TL}$ and it is below described. After having defined the complex polarization mfactors:

$$(R_i)_{TL} \,\Delta\, \frac{[1-(r_i)_{TL}]}{[1+(r_i)_{TL}]}$$

$$R \,\Delta\, \frac{[1-\overline{r}]}{[1+\overline{r}]}$$

where:

- $(r_i)_{TL}$ is the ellipticity ratio of the polarization state of the i-th sample, at the output of linear-PVT;
- $\overline{r}$ is the transition control parameter [6] (if $(r_i)_{TL} < \overline{r}$ the location of sample polarization state converges to the left handed circular polarization, and if $(r_i)_{TL} > \overline{r}$ it diverges) ;

the non-linear PVT operator, differently from the conventional one [6], is chosen as:

$$M_{NL} = \frac{1 + |(R_i)_{TL}|^2}{G + |(R_i)_{TL}|^2} \begin{bmatrix} G & 0 \\ 0 & 1 \end{bmatrix}$$

where

$$G \,\Delta\, G[(r_i)_{TL},(\phi_i)_{TL},\overline{\phi},m,\overline{r}] = \left[\frac{R}{(R_i)_{TL}}\right]^M$$

The non-linear PVT operator then modifies the polarisation of each input and

$$M = \frac{m}{2} [1 + \cos 4(\phi_i - \overline{\phi})]$$

where m is still the gradient of the transformation control parameter [6].

In this case, differently from the conventional non-linear PVT, we note that the transformation operator depends also on ϕ_i and ϕ.

The performance of this filter were tested through the processing of experimental data acquired by means of an ATC radar system, modified for receiving dual polarized signals. The results, which refer to simulated operation of the polarization filter, have been reported in a previous paper [3].

Such results demonstrate that the proposed non-linear polarization filter is effective in improving signal-to-ground clutter ratio. Moreover large signal-to-ground clutter ratio improvements are obtained when MTI pre-processing of input signals is jointly applied on the receiving channels.

REFERENCES

[1] Giuli D.,"Diversity polarization in radars", *Proc. of IEEE*, vol. 74, n.2, Feb. 1982.

[2] Giuli D., Rossettini A., "Analysis of radar receivers for dual polarization target detection", *Proc. of International Conference Radar-87*, London (U.K.), 19-21 October 1987.

[3] Giuli D., Gherardelli M., Freni A., Fossi M. :"Adaptive polarisation for rejection of ground clutter", *L'Onde Electrique*, Vol. 69, n. 6, Nov.-Dec. 1989.

[4] Gherardelli M., "Adaptive polarisation suppression of intentional radar disturbance", *IEE Proc.*, Part F., vol. 137, 1990.

[5] Gherardelli M., Giuli D., Fossi M., "Double-polarisation radar measurements", *Electronics Letters*, vol. 20, n. 15, July 1984.

[6] Poelman A.J., Guy J.R.F. :"Non-linear polarisation-vector translation in radar systems.", *IEE Proc.*, Pt. F, vol. 131, 1984

[7] Poincaré H., "*Théorie Mathématique de la Lumière*", Paris (France), George Carre, 1892.

[8] Giuli D., Fossi M., Gherardelli M., "Polarization behaviour of ground clutter"

MEASURED SMALL- AND BROADBAND SCATTERING MATRIX DATA, THEIR MODELING AND PROCESSING

Dr.-Ing. G. Wanielik*

1. Introduction

The signal processing part of polarimetric radars works on multivariate vector sequences $\underline{s}(i)$, i=0,...,N-1, or partitions of such scattering matrix vectors

$$\underline{s}(i)=(S_{11}(i),S_{21}(i),S_{12}(i),S_{22}(i))^T=(s_1(i),s_2(i),...,s_m(i))^T,\ m=1,..,4 \quad (1)$$

where m=4,3,2 if the polarimetric radar is bistatic, monostatic ($S_{12}=S_{21}$) or only polarimetric on receive. Another distinction has to be made depending on the meaning of the index i. In the case of a smallband pulse radar the index i represents SM-measurements at different time instances t_i. In the context of broadband polarimetric radars, however, the index i represents a SM-measurement taken at different carrier frequencies f_i. The description and modeling of both types of SM-sequences and their relations to the polarimetric signal processing are the subject of this paper.

2. Description and Modeling of Measured Smallband SM-Data

In this first part I discuss descriptions and models of measurement data obtained from a smallband polarimetric pulse radar. Usually polarimetric pulse radars transmit a sequence of pulsed wave pairs (the first horizontally, the second vertically polarized) at the same carrier frequency and receive an object-specific transformed SM-sequence $\underline{s}(i)$. One way to describe such measurement sequences $\underline{s}(i)$, i=0,...,N-1, is to use the autocorrelation matrices with lag k, k≥0, which are defined by $\underline{R}_{ss}$ in equation (2) and which can be estimated by $\hat{\underline{R}}_{ss}$ as shown in equation (3):

$$\underline{R}_{ss}(k) = \langle \underline{s}(i+k) \cdot \underline{s}^{*T}(i) \rangle \quad (2)$$

$$\hat{\underline{R}}_{ss}(k) = \frac{1}{N-k-1} \cdot \sum_{i=0}^{N-k-1} \underline{s}(i+k) \cdot \underline{s}^{*T}(i) \quad (3)$$

In this formula the character '*' represents the complex conjugate, 'T' the transpose operation and ⟨·⟩ the time average. A special autocorrelation matrix of equation (2) is frequently used in radar polarimetry. This is the coherency matrix $\underline{J}_s=\underline{R}_{ss}(0)$ for which the correlation matrix $\hat{\underline{R}}_{ss}(0)$ with time

* Daimler-Benz AG, Research Institute, Wilhelm-Runge-Str.11, D-7900 ULM, Germany, phone: 0731/505 2120, fax: 0731/505 4105