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EXPERIMENTAL RESULTS ON DUAL-POLARIZATION BEHAVIOR OF GROUND CLUTTER

M. Fossi, M. Gherardelli, P. Giannino and D. Giuli
(Department of Electronics Engineering, University of Florence, Florence, Italy)

ABSTRACT

In this paper some results are presented which refer to dual-polarization ground clutter measurements carried out with a radar system equipped with two orthogonally circularly polarized receiving channels. A statistical analysis of the parameters which describe the polarization behavior of ground clutter during dwell-time has been performed. The results which have been obtained are summarized in this paper.

INTRODUCTION

Conventional radar systems operate with fixed single-polarized antennas for transmission as well as for reception. Therefore, the received backscattered wave, which is completely described in terms of the related field vector, is converted to a scalar signal. In such a way some information is lost. To overcome this limitation, the entire information content of the backscattered wave has to be acquired by retaining its polarization through a vector measurement process. There are some reasons which make polarization diversity techniques potentially useful in radar systems. In some cases, it may occur that, due to radar system design constraints, the usual signal parameters (e.g. Doppler frequency, bearing, etc.) cannot be fully exploited to provide their inherent signal discrimination capabilities in the presence of interfering radar returns. In these cases, the use of polarization parameters becomes the unique solution which can enhance radar discrimination capabilities[1]. A critical point for the application of polarization diversity techniques is the actual polarization behavior of different objects. Available information, generally based on radar measurements, mainly refers to the statistical parameters of polarization evaluated through long-term averages and space independent observations. Conversely, the performance evaluation of adaptive polarization techniques requires a deeper knowledge of short-term polarization behavior, as during the dwell-time of a scanning antenna illuminating the target. For this purpose, this paper presents some measurement results which describe the statistical polarization behavior of S-band, short-term, returns from ground clutter. These results have been obtained through off-line analysis of recorded data obtained from measurements carried out with a low-resolution, fixed circular polarization transmission, ATC radar, suitably modified for double-polarization reception[2].

ANALYTICAL TOOLS

Mainly due to antenna scanning, the e.m. backscattering from ground presents an intrinsic degree of non-stationarity of polarization during antenna dwell-time. Approximately, the concept of partially polarized wave may apply in characterizing the polarization properties of the observed ground clutter. Based on this concept, some analytical and graphical tools can be applied in describing completely and partially polarized waves which are now briefly recalled. Given the four parameters p = "amplitude", α = "absolute phase angle", ϕ = "polarization orientation angle" and τ = "ellipticity polarization angle", they completely describe the vector $\underline{H}$ of a plane wave according to the following expressions:

$$\underline{H} = p\, e^{j\alpha} \cdot \underline{h} \tag{1a}$$

$$\underline{h} = \begin{bmatrix} h_H \\ h_V \end{bmatrix} = \begin{bmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} \cos\tau \\ j\sin\tau \end{bmatrix} \tag{1b}$$

with ϕ and τ representing the wave polarization. The Poincaré sphere representation[3], normalized with respect to the amplitude parameter of polarization (p = 1), which utilizes only two parameters, ϕ and τ, can still be used for representing the polarization state $\underline{h}$ of the wave. Each polarization state $\underline{h}$ is represented on the Poincaré sphere by a point P of spherical coordinates (1, 2ϕ, 2τ). A useful plane representation of the Poincaré sphere is the so-called polarization chart, which is the orthogonal projection of the sphere surface on its equatorial plane (z = 0) (Fig. 1). Completely polarized waves are suitably represented by (1), where the two parameters ϕ and τ are assumed to be time-invariant. The polarization state $\underline{h}$ of such a wave is univocally represented by a fixed point on the polarization chart. Partially polarized waves are also represented by expressions (1), when the two components of the polarization state vector $\underline{h}$ are assumed to be time-variant. In such a case, it is usually assumed that h_H and h_V are zero-mean complex random processes. Consequently, the representative points of such a polarization on the polarization chart are time varying. A useful description of such a polarization state is expressed by the second order statistics, which define the so-called Stokes vector $\underline{g}$, as:

$$\underline{g} \triangleq \begin{bmatrix} g_0 \\ g_1 \\ g_2 \\ g_3 \end{bmatrix} \triangleq \begin{bmatrix} <h_H h_H^*> + <h_V h_V^*> \\ <h_H h_H^*> - <h_H h_H^*> \\ 2<Re(h_H^* h_V)> \\ 2<Im(h_H^* h_V)> \end{bmatrix} \tag{2}$$

where $<\cdot>$ denotes time average, and the component g_0, which represents the total average power of the wave, meets the following condition[4]:

$$g_o^2 \geq g_1^2+g_2^2+g_3^2 \qquad (3)$$

In (3) the equality holds when the wave is completely polarized. In such a case, the representative point onto the Poincaré sphere can be expressed in terms of Stokes parameters by $P \equiv (g_1/g_o,\ g_2/g_o,\ g_3/g_o)$. Conversely, if the equalities $g_1=g_2=g_3=0$ hold in (3), the wave is completely unpolarized, and a random distribution of points results on the Poincaré sphere. In terms of the Stokes vector representation, a partially polarized wave can be uniquely decomposed as:

$$\underline{g} = [g_{op}, g_1, g_2, g_3]^T + [g_o - g_{op}, 0, 0, 0]^T \qquad (4)$$

where $g_{op} = (g_1^2+g_2^2+g_3^2)^{1/2}$ and $g_o - g_{op}$ are the powers contained in the totally polarized and unpolarized wave components, respectively. Accordingly, a degree of polarization ρ is defined as:

$$\rho \triangleq \frac{g_{op}}{g_o} = \frac{(g_1^2+g_2^2+g_3^2)^{1/2}}{g_o} \qquad (5)$$

STATISTICAL DATA PROCESSING AND FEATURES

The submitted statistics refer to a collection of experimental data carried out by a low-resolution, S-band, ATC radar circularly polarized in transmission (see Table 1), scanning a ground surface characterized by low relief (suburban area in the city of Rome). The acquired data, pertaining to the polarizazion state of several radar bins, have been gathered in spatial windows of 16 sweeps x 1 range bin, corresponding to the dwell-time on point targets. With reference to the polarization chart representation of such a sequence of samples, two main features have been observed: the first (Fig. 1), corresponding to extended ground clutter phenomena, points out that the polarization state of samples lines up along some preferred direction; the other (Fig. 2), pertaining to point clutter phenomena, exhibits a quite clustered distribution of the polarization state of the samples around their polarization mean state ($P \equiv (g_1/g_o,\ g_2/g_o,\ g_3/g_o)$ on the Poincaré sphere). Such phenomena become more evident as the average power g_o of the window increases. In order to statistically evaluate the above-mentioned features, a linear translation of the polarization state of the samples pertaining to each analyzed window has been performed on the polarization chart, so as to map the mean polarization pertaining to each observed data sequence on the circularly left-handed polarization point ($\tau = -45°$, center point of the polarization chart). As a consequence, straightforward expressions for some parameters, wnich statistically express the above-mentioned features, can be defined. Precisely: i) With reference to the distributed clutter phenomenon, we define an angular orientation offset $\Delta\phi_i \triangleq \phi_i - \overline{\phi}$ for the i-th sample with respect to a leading (average) orientation angle $\overline{\phi}$ of the analyzed data sequence; the computation of parameter $\overline{\phi}$ is a minimum problem for the function:

Table 1: Radar acquisition system features

Peak power	500 kW
Operating frequency	2700–2900 MHz
Pulse width	1 μs
Pulse repetition frequency	1000 Hz
Antenna polarization in transmission	Right-handed circular
Antenna polarization on reception	Elliptical
Type of coverage	modified $cosec^2$
Antenna scan rate	15 r.p.m.
Antenna gain	33.5 dB
3-dB horizontal beamwidth	1.45 ± 0.05 degrees
3-dB vertical beamwidth	5 ± 0.2 degrees
Main sidelobes	lower than -25dB
A/D signal converter	8 bits

$$\sigma_\phi = [\frac{1}{N}\sum_{i=1}^{N} (\phi_i - \bar{\phi})^2]^{1/2} \qquad (6)$$

where the standard deviation σ_ϕ represents the statistical parameter evaluated for the distributed ground clutter phenomenon; ii) With reference to the point clutter phenomenon, we define a spreading angle $\Delta\tau_i = \tau_i + 45°$ of the i-th sample, with respect to the mean polarization $\bar{\tau} = -45°$ of the analyzed window. In such a case, the selected statistical parameter is the standard deviation σ_τ:

$$\sigma_\tau = [\frac{1}{N}\sum_{i=1}^{N} (\tau_i - \bar{\tau})^2]^{1/2} \qquad (7)$$

Moreover this parameter roughly expresses --in the case of distributed clutter-- the standard deviation of the samples along the prevalent (average) radius corresponding to the angle $\bar{\phi}$. Fig. 3 concisely describes these parameters, in connection with a typical window relevant to a disstributed clutter phenomenon (Plots P_i represent the polarization of each echo sample during dwell-time).

RESULTS AND REMARKS

The statistical parameters previously defined have been evaluated for the set of windows extracted from the acquired data; except for the point clutter phenomenon, which mainly attains the range 30-40 dB of C/N, distinct estimates of such parameters have been accomplished, grouping data sequences of similar clutter-to-noise ratio C/N values (10 dB step). Figs. 4-7 present the histograms relevant to sample estimates, concerning some of the observed ground clutter phenomena. In Figs. 4 and 6 the histograms of σ_ϕ and σ_τ evaluated with 405 independent windows are reported for ground clutter in the 10-20 dB range of C/N. The analogous histogram evaluated with 1820 independent windows is reported in Figs. 5 and 7 for ground clutter in the 40-50 dB range of C/N. Particularly, Figs. 4 and 5 show that the window sample alignment along the prevalent direction increases as the C/N ratio increases, this effect is emphasized by the correspondent decrease of the σ_ϕ parameter value distribution. A similar, but less evident, effect is shown by the behavior of the σ_τ parameter, which denotes a parallel decrease in the extent of the sample distribution along the prevalent direction $\bar{\phi}$ (Figs. 6, 7). Another statistics relevant to the distribution of values of the polarization degree ρ (5), evaluated for all (3616) 16-sample windows extracted from the entire acquired data set, has been performed, and the corresponding histogram is shown in Fig. 8. We can observe a distribution clustered on high values of the degree of polarization. A parallel investigation concerning the scan-to-scan stationarity of the polarization state of each analyzed window has been accomplished. The observed results indicate frequent high stationarity polarization behaviors on the same window from one scan to another, corresponding to high C/N ratios. This result, together with the above recognition of both spatially narrow patterns on the polarization domain and a high polarization degree during dwell-time, points out potentially useful adaptive ground clutter cancellation capabilities, especially with strong clutter.

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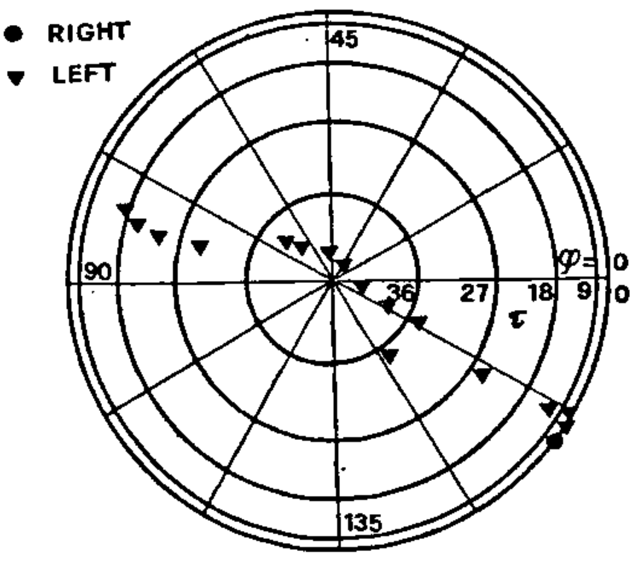

Fig. 1 Polarization of successive echo samples during dwell time (distributed clutter)

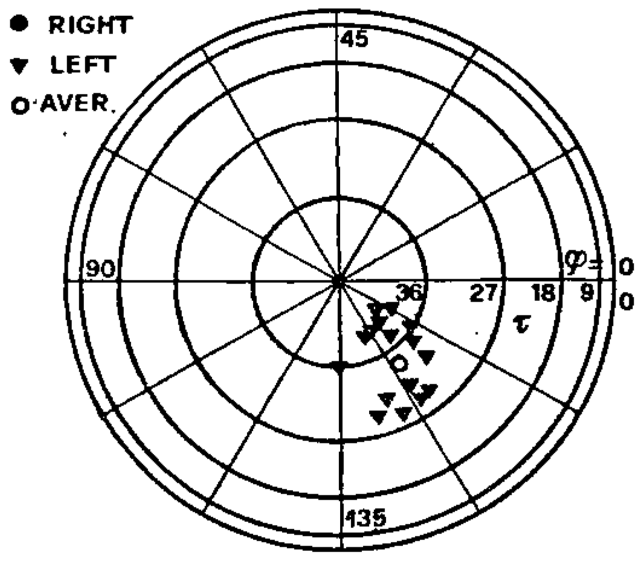

Fig. 2 Polarization of successive echo samples during dwell time (point clutter)

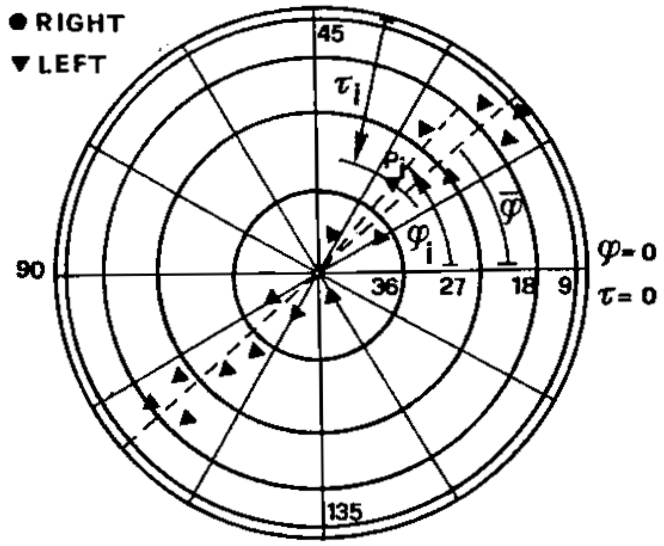

Fig. 3 Statistical polarization parameters defined through the polarization chart.

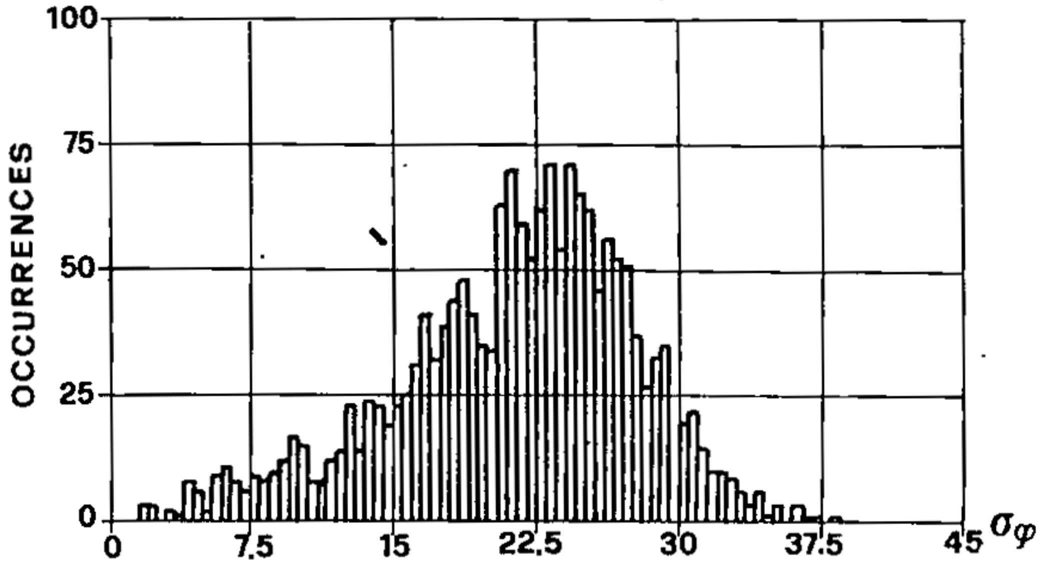

Fig. 4 Histogram of σ_ϕ for ground clutter (C/N = 10-20 dB)

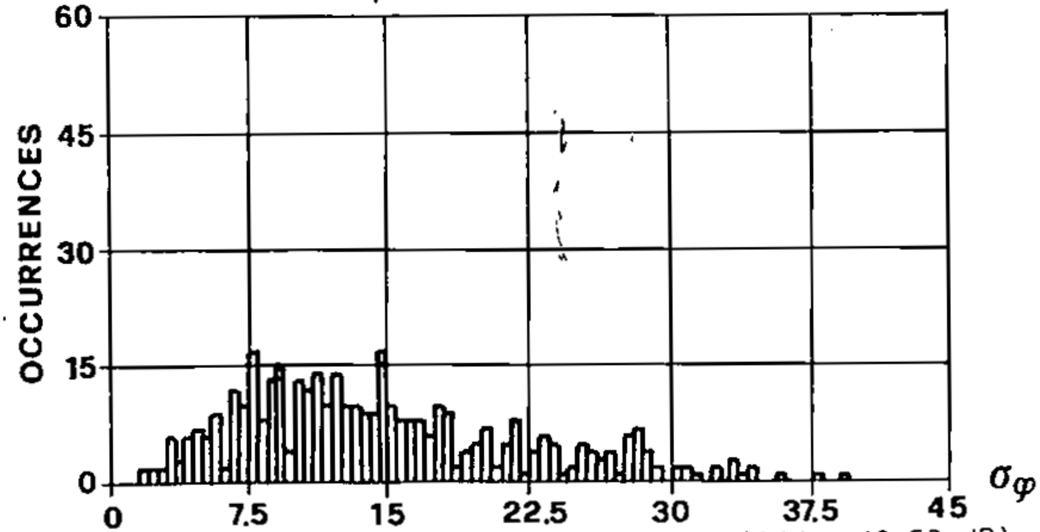

Fig. 5 Histogram of σ_ϕ for ground clutter (C/N = 40-50 dB)

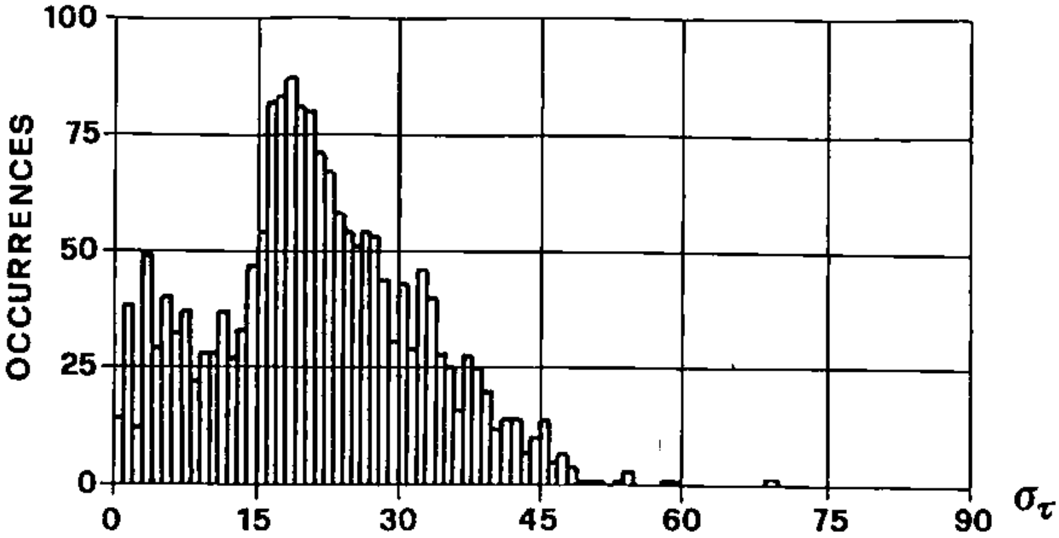

Fig. 6 Histogram of σ_τ for ground clutter (C/N = 10-20 dB)

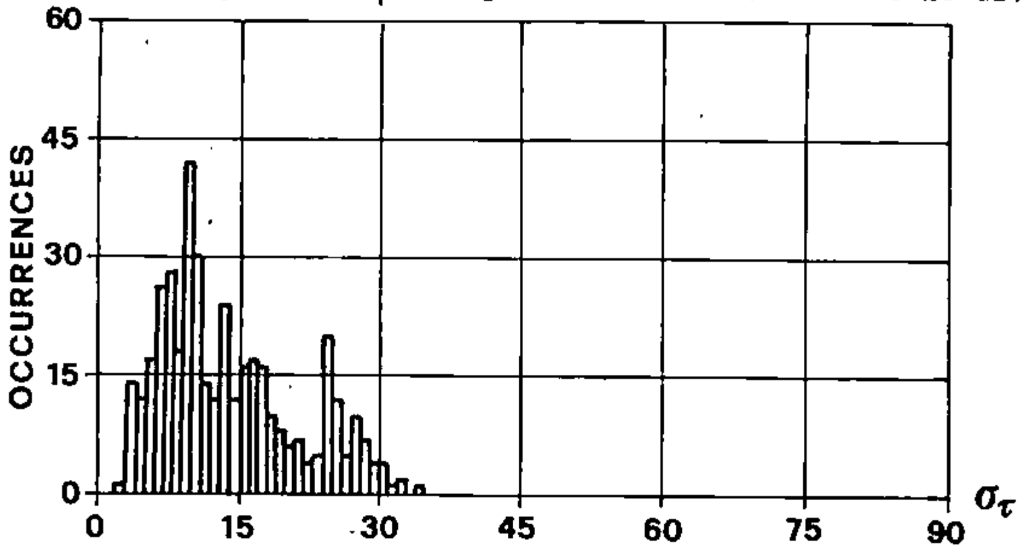

Fig. 7 Histogram of σ_τ for ground clutter (C/N = 40-50 dB)

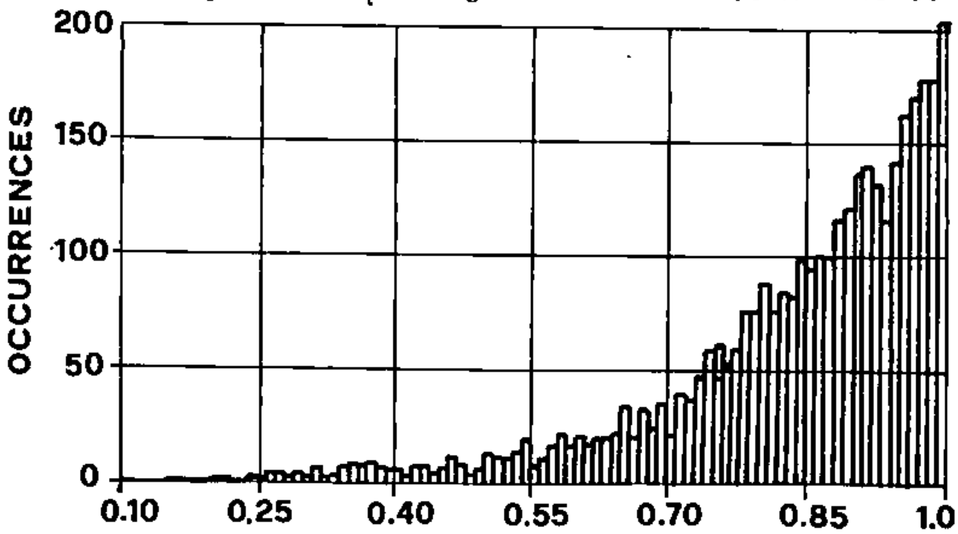

Fig. 8 Histogram of the degree of polarization (entire set of ground clutter sequences)