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Estimation of the phase shift between simultaneously transmitted H and V in the SHV mode

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Abstract

A method for measuring the phase shift between the horizontal and vertical polarizations, simultaneously transmitted by weather radars using the SHV method for polarimetric measurements, is presented. The method is based on the 3-PolD method and requires the antenna to be azimuthally rotated when pointing to the zenith as for Z_{dr} calibration.

1 Introduction

Different methods have been proposed to perform polarimetric measurements of weather targets. The one most frequently used is the SHV method [1]. This method provides measurements of the reflectivity, the differential reflectivity, the co-polar correlation coefficient and the differential phase shift by simultaneously transmitting and receiving horizontal and vertical polarizations.

Implementation of the SHV method requires a simpler hardware as compared to the hardware required for the implementation of the other methods proposed. However, this simpler hardware comes at the expense of other properties. The SHV method does not provide all polarimetric parameters (the linear depolarization ratio cannot be determined, neither the canting angle could be determined). Besides, the estimates of the polarimetric parameters are biased as a consequence of assuming a zero cross-polar power. Finally, its demands on the cross-polar radiation of the antenna to ensure a given accuracy of the polarimetric measurements are significantly higher than those required by the other polarimetric measurement methods proposed [2], [3].

In [4], [5] it is shown that the error in the differential reflectivity and the co-polar correlation coefficient estimates depends on the phase shift between the simultaneously transmitted horizontal and vertical polarizations. In general, maximum errors occur if the transmitted polarization is circular, that is the phase shift between the H and V polarizations equals $\pm 90^o$. Determining this phase shift is not easy and usually is not provided in the radar specifications.

In this paper a method for measuring the phase shift between the simultaneously transmitted H and V polarizations is presented. The method has been developed considering the radar system has implemented the SHV method, the antenna can be pointed to the zenith and rotated azimuthally 360 degrees. It is important to point that this last requirement is not as stringent as it may appear since most current systems can already point the antenna to the zenith and rotate it azimuthally to perform the Z_{dr} calibration.

The basic theory used to develop the algorithm for the measurement of the phase shift between H and V polarizations is described in section 2. The algorithm and the steps for its implementation are summarized in section 3. Some results with simulated data are presented in section 4 and finally the conclusions are presented in section 5.

2 Basic Polarimetric Theory

Let us consider that the transmitting/receiving antennas are horizontally and vertically polarized as in SHV radar systems. The radiated field, with polarization $\hat{\alpha}$, can be expressed as:

$$E^t = U_\alpha \begin{bmatrix} 1 \\ 0 \end{bmatrix} \tag{1}$$

with U_α the unitary matrix to change from the $(\hat{\alpha}, \hat{\alpha}^\perp)$ polarization basis to the HV polarization basis. The co- and cross-polar voltages at reception V_α and $V_{\alpha^\perp}$, due to backscattering from hydrometeorological targets, are:

$$\begin{bmatrix} V_\alpha \\ V_{\alpha^\perp} \end{bmatrix} = U_\alpha^t \mathbf{S}_{hv} U_\alpha \begin{bmatrix} 1 \\ 0 \end{bmatrix} \tag{2}$$

where $\mathbf{S}_{hv}$ is the target scattering matrix that includes propagation effects. Note that radar constants have been dropped out for simplicity.

Since backscattering from meteorological targets is random in nature, it is characterized, nor by the scattering matrix, but by the polarimetric covariance matrix

$$\mathbf{C}_{HV} = \mathrm{E}\{ \begin{bmatrix} S_{hh} \\ \sqrt{2}S_{hv} \\ S_{vv} \end{bmatrix} \begin{bmatrix} S_{hh}^* & \sqrt{2}S_{hv}^* & S_{vv}^* \end{bmatrix} \} \tag{3}$$

that contains the second order moments of the scattering matrix elements S_{hh}, S_{hv}, S_{vv}.

Second order moments of the received voltages at the two polarimetric channels

$$\mathbf{V}_\alpha = \mathrm{E}\{ \begin{bmatrix} V_\alpha & V_{\alpha^\perp} \end{bmatrix} \begin{bmatrix} V_\alpha^* \\ V_{\alpha^\perp}^* \end{bmatrix} \} \tag{4}$$

are linearly related to the polarimetric covariance matrix [6]:

$$\mathrm{vec}(\mathbf{V}_\alpha) = (P \otimes P)(\mathbf{M}_\alpha^* \otimes \mathbf{M}_\alpha)\mathrm{vec}(\mathbf{C}_{HV}) \tag{5}$$

where $\mathrm{vec}(\cdot)$ indicates the matrix has been vectorized by stacking its columns and

$$\mathbf{M}_\alpha = (U_\alpha^t \otimes U_\alpha^t) \begin{bmatrix} 1 & 0 & 0 \\ 0 & \sqrt{2} & 0 \\ 0 & \sqrt{2} & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{6}$$

$$P = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \otimes \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \tag{7}$$

As it can be drawn from [6] if different polarized fields ($\hat{\alpha 1}$, $\hat{\alpha 2} \cdots \hat{\alpha N}$) are transmitted, the second order moments of the received voltages will relate to the polarimetric covariance matrix by

$$\mathbf{V} = \begin{bmatrix} \mathrm{vec}(\mathbf{V}_{\alpha 1}) \\ \mathrm{vec}(\mathbf{V}_{\alpha 2}) \\ \vdots \\ \mathrm{vec}(\mathbf{V}_{\alpha N}) \end{bmatrix} = \begin{bmatrix} (P \otimes P)(\mathbf{M}_{\alpha 1}^* \otimes \mathbf{M}_{\alpha 1}) \\ (P \otimes P)(\mathbf{M}_{\alpha 2}^* \otimes \mathbf{M}_{\alpha 2}) \\ \vdots \\ (P \otimes P)(\mathbf{M}_{\alpha N}^* \otimes \mathbf{M}_{\alpha N}) \end{bmatrix} \mathrm{vec}(\mathbf{C}_{HV})$$

$$= \mathbf{H}\mathrm{vec}(\mathbf{C}_{HV}) \tag{8}$$

Consequently

$$\mathrm{vec}(\mathbf{C}_{HV}) = \mathbf{H}^\sharp \, \mathbf{V} \tag{9}$$

with $\mathbf{H}^\sharp$ any left pseudoinverse of $\mathbf{H}$.

3 Algorithm Implementation

The sample estimator of the second order moments of the received voltages $\overline{\mathbf{V}}$ is an unbiased estimator [7], that is

$$\mathrm{E}\{\overline{\mathbf{V}}\} = \mathbf{H} \cdot \mathbf{C}_{HV} \tag{10}$$

On the other hand, an alternative estimate of the second order moments of the received voltages $\hat{\mathbf{V}}$ can be defined based on eqs. (8) and (9) as

$$\hat{\mathbf{V}} = \overline{\mathbf{H}}\, \overline{\mathbf{C}_{HV}} \tag{11}$$

where $\overline{\mathbf{H}}$ is the matrix built from knowledge of the transmitted polarizations and $\overline{\mathbf{C}_{HV}}$ is the weighted linear least estimate of $\mathbf{C}_{HV}$:

$$\overline{\mathbf{C}_{HV}} = \overline{\mathbf{H}}^\sharp \, \overline{\mathbf{V}} \tag{12}$$

The expected value of $\hat{V}$ is given by:

$$\mathrm{E}\{\hat{\mathbf{V}}\} = \mathrm{E}\{\overline{\mathbf{H}}\overline{\mathbf{H}}^\sharp \overline{\mathbf{V}}\} = \overline{\mathbf{H}}\overline{\mathbf{H}}^\sharp \mathbf{H} \cdot \mathbf{C}_{HV} \tag{13}$$

Evidently, the expected values of $\overline{\mathbf{V}}$ and $\hat{\mathbf{V}}$ will be equal only if the transmitted polarizations are correctly known, that is, if $\overline{\mathbf{H}}$ equals $\mathbf{H}$. This fact can be used to determine the transmitted polarizations if enough data is available. The transmitted polarizations are those minimising the difference between the sample mean of $\overline{\mathbf{V}}$ and $\hat{\mathbf{V}}$.

To determine the phase shift between the horizontal and vertical polarization the radar is pointed to the zenith. Therefore, as the antenna is azimuthally rotated the transmitted polarization will rotate either for the LDR or the SHV modes (unless the phase shift between H and V equals $\pm 90^o$).

Transmission of linear polarizations at two different azimuth angles and of H+V at another two azimuth angles is proposed. Then, the difference between the sample means of $\overline{\mathbf{V}}$ and $\hat{\mathbf{V}}$ will be calculated considering different values of the phase shift between H and V when building matrix $\overline{\mathbf{H}}$. The value minimizing the difference is the proposed estimator for the phase shift between H and V.

4 Results

To test the method data has been simulated. For the simulations typical polarimetric parameters of drizzle and rain have been considered. The transmitted polarizations considered are linear slanted 30^o, vertical, H+V and H+V rotated 60^o.

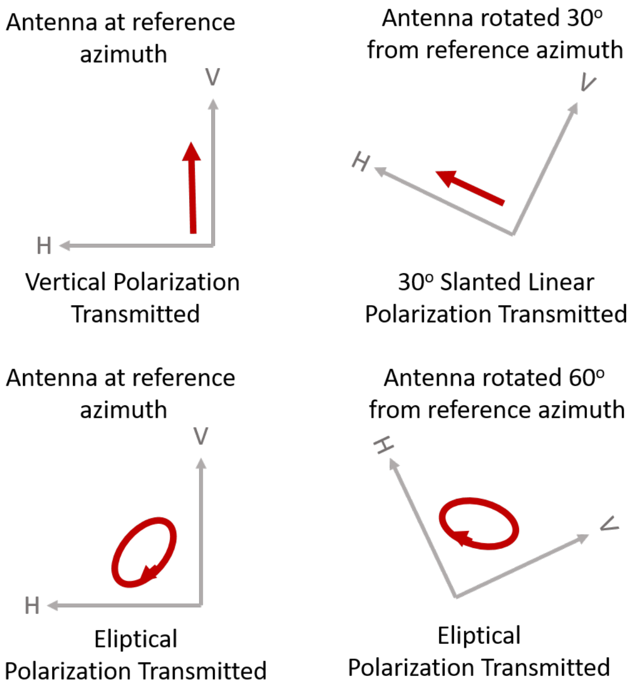

Figure 1. Polarizations transmitted for a "true" phase shift between H and V of 45^o and different azimuthal rotations of the antenna

Three different phase shifts between H and V were used for the simulations: 0^o, 45^o and 90^o.

The normalized magnitude of the error (in dBs) between $\overline{\mathbf{V}}$ and $\hat{\mathbf{V}}$ as a function of the phase shift between H and V used to calculate $\overline{\mathbf{H}}$ is shown in Figures 2-4.

The results shown indicate a good performance of the method proposed. It is important to point that the large

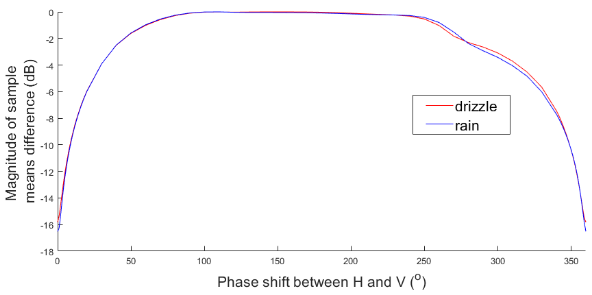

Figure 2. Magnitude of the difference between sample means of $\hat{V}$ and $\overline{V}$ in dB for a true value of the transmitted phase shift between H and V of 0^o.

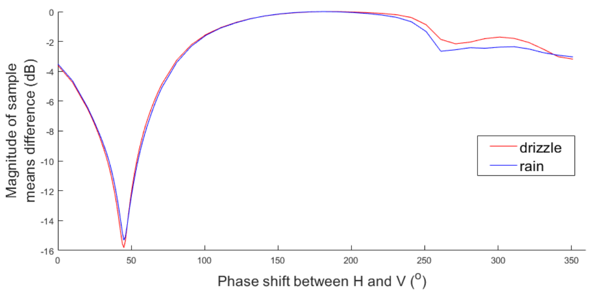

Figure 3. Magnitude of the difference between sample means of $\hat{V}$ and $\overline{V}$ in dB for a true value of the transmitted phase shift between H and V of 45^o.

amount of data required by the proposed method implies a total observation time of about 4 minutes. During this time the statistical characteristics of the targets observed must remain invariant.

5 Conclusions

A method to determine the phase shift between simultaneously transmitted H and V polarizations for weather radars using the SHV method has been developed.

The method has been developed considering the current capabilities of nowadays radars. Implementation of the method does not require adding hardware to the radar or external calibrated targets. It is based on the statistical properties of the received voltages from weather targets. The data for the method is obtained with the operation mode used for Z_{dr} calibration.

The method, as it is proposed in this paper requires previous calibration of Z_{dr}. However, it is rather straightforward to extend the method to simultaneously determine the phase shift and power imbalance between H and V channels. This work is ongoing.

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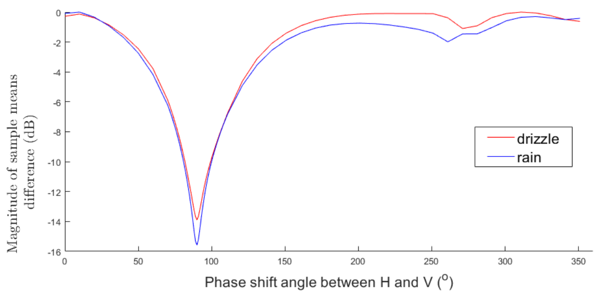

Figure 4. Magnitude of the difference between sample means of $\hat{V}$ and $\overline{V}$ in dB for a true value of the transmitted phase shift between H and V of 90^o.

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