P1.3 IMPROVEMENT OF POLARIMETRIC RADAR CALIBRATION FOR ATMOSPHERIC RADARS

D. N. Moisseev*, C. M. H. Unal, H. W. J. Russchenberg and L. P. Ligthart
IRCTR, Delft University of Technology, The Netherlands

1. INTRODUCTION

Conventional polarimetric radar calibration techniques are based only on measurements of calibration targets located in the boresight direction of the antenna, further in the article they are referred as point target calibration methods. These calibration techniques have poor performance for atmospheric radars, since weather echoes are spatially distributed and thus the complete antenna pattern contributes to their measurements.

In this article we propose a correction method to the point target polarimetric calibration technique. Using this correction technique we are able to take into account the distributed nature of atmospheric targets. This correction is based on light rain measurements with the radar pointed to the zenith. For these measurements rain can be considered as an isotropic target, this assumption is checked by changing the antennas azimuth angle. Furthermore, we calculate the actual antenna polarization isolation level and amount of decorrelation between co- and cross- polar measurements. Based on these calculations correction parameters are introduced into the antenna distortion matrices obtained from the conventional polarimetric radar calibration.

In this article we will show that this correction technique improves cross-polar measurements. All measurements in this work are made with the Delft Atmospheric Research Radar (DARR), which is an *S*-band Doppler polarimetric radar.

2. POINT TARGET RADAR CALIBRATION

For an ideal polarimetric radar system the measured target scattering matrix **M** is equal to the actual scattering matrix **S** of the target. In the case of real radar systems it is common to model the measured scattering matrix as (Sarabandi et al. 1990; Unal et al. 1994):

$$\mathbf{M} = \mathbf{RST} \qquad (1)$$

where **R** and **T** are the antennas distortion receive and transmit *2x2* matrices respectively. Because we only discuss relative polarimetric calibration in this paper, the coefficient that corresponds to the absolute value of the received voltage in (1) is omitted. The matrices **R** and **T** give the transformation of ideal receive and transmit polarization states (usually *h-v* linear polarizations) to the actual polarization states of the antenna.

The formulation (1) introduces the polarimetric radar calibration principle. It can be seen that for the unambiguous solution of (1) for **R** and **T** at least three different radar targets are required. If the radar system can be treated as reciprocal ($\mathbf{M}^T = \mathbf{M}$), one antenna is used for transmitting and receiving, (1) can be simplified as follows (Unal et al. 1994):

$$\mathbf{M} = \mathbf{T}^T \mathbf{S} \mathbf{T} \qquad (2)$$

where

$$\mathbf{T} = \begin{bmatrix} 1 & d_2 \\ d_1 & f \end{bmatrix} \qquad (3)$$

d_1 and d_2 express the coupling between the radar polarization channels and f is the co-polar channel imbalance.

The formulation (2), taking into that **S** is a symmetric matrix and (3), can be rewritten as:

$$\vec{m} = \begin{bmatrix} 1 & 2d_1 & d_1^2 \\ d_2 & f + d_1 d_2 & f d_1 \\ d_2^2 & 2 f d_2 & f^2 \end{bmatrix} \cdot \vec{s} \qquad (4)$$

where $\vec{s}$ and $\vec{m}$ are vector representations of **S** and **M**, e.g. $\vec{s} = \begin{bmatrix} S_{hh} & S_{hv} & S_{vv} \end{bmatrix}^T$.

It is common to use the polarimetric radar covariance matrix $\mathbf{C} = \left\langle \vec{s} \cdot \vec{s}^{\,+} \right\rangle$ (Ryzhkov, 2001) for the description of atmospheric targets. To obtain the calibrated covariance matrix formulation, (4) should be changed as:

$$\vec{c}_m = \mathbf{D} \cdot \vec{c}_s \qquad (5)$$

where $\vec{c}_m$ and $\vec{c}_s$ are vector representations of the measured and actual target covariance matrices, and the distortion matrix **D** is defined as:

$$\mathbf{D} = \begin{bmatrix} 1 & 2d_1 & d_1^2 \\ d_2 & f + d_1 d_2 & f d_1 \\ d_2^2 & 2 f d_2 & f^2 \end{bmatrix} \otimes \begin{bmatrix} 1 & 2d_1 & d_1^2 \\ d_2 & f + d_1 d_2 & f d_1 \\ d_2^2 & 2 f d_2 & f^2 \end{bmatrix}^* \qquad (6)$$

here ⊗ denotes Kronecker product and * represents complex conjugate.

* *Corresponding author address: Dmitri Moisseev,* IRCTR, Faculty of Information Technology and Systems, Delft University of Technology, Mekelweg 4, 2628 CD Delft, The Netherlands; e-mail: D.Moisseev@its.tudelft.nl

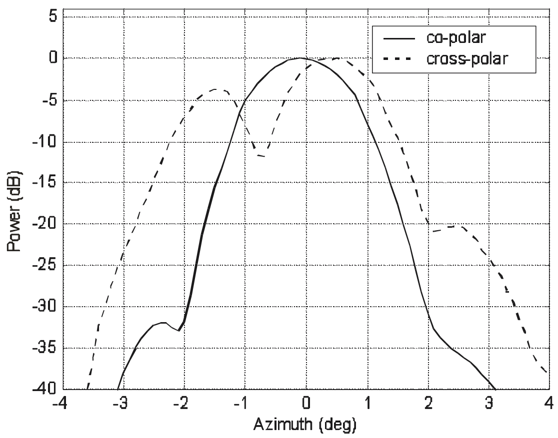

Fig. 1 Two-way antenna patterns (45 degrees plane). The cross-polar antenna pattern is weighted to have the same maximum value as the co-polar antenna pattern.

The formulations (2) and (5) will be used further in this paper as an example of point target polarimetric radar calibration approach.

3. DISTRIBUTED TARGET MEASUREMENTS; IMPLICATIONS TO POLARIMETRIC CALIBRATION

For the distributed target measurements the complete antenna patterns contribute. In this case the influence of the antenna to the polarimetric measurements can be formulated by the integral equation (Blanchard and Jean, 1983):

$$\mathbf{M} = \iint \left[f_r(q,f) \right] \cdot \mathbf{S}(q,f) \cdot \left[f_t(q,f) \right] \sin q dq df \qquad (7)$$

where $\left[f(q,f) \right]$ is the antenna distortion matrix defined for all azimuth q and elevation angles f, $\mathbf{S}(q,f)$ is the scattering matrix of an extended target as a function of the azimuth and elevation.

It can be seen that (7) coincides with (1) only if the target dimensions are small $\mathbf{S}(q,f) = \mathbf{S}$. Since, the objects of interest for atmospheric remote sensing are extended objects, the formulation (1) is insufficient. Thus, it is necessary to study the influence of the distributed nature of objects on polarimetric measurements.

3.1 *Estimation of the differential reflectivity Zdr*

The differential reflectivity is the ratio of $\left\langle |S_{hh}|^2 \right\rangle$ to $\left\langle |S_{vv}|^2 \right\rangle$. From (4) it can be seen that for the radars with good polarization isolation the accuracy of *Zdr* measurements is given by the accuracy of the channel imbalance *f*.

In order to see the influence of the complete antenna pattern on *f* the antenna patterns of DARR were used. Based on them it was estimated that the difference between channel imbalances obtained from one point measurement and full antenna pattern is small. This difference leads to the error in the estimation of *Zdr* in the order of 10^{-2} dB. This accuracy is satisfactory for the most analysis and thus a point target polarimetric radar calibration can be used for the estimation of *Zdr.*

3.2 Accuracy of c*ross-polar measurements*

It was shown (Blanchard and Jean, 1983, Moisseev, et al., 2000) that the antenna pattern has a strong influence on the cross-polar measurements of distributed targets. Two main effects that influence these measurements were identified.

The first effect is that the polarization isolation of the antenna, minimum measured value of $\left\langle |M_{hh}|^2 \right\rangle \Big/ \left\langle |M_{hv}|^2 \right\rangle$, is defined at the boresight direction for point target polarimetric calibration. However, for parabolic antennas the boresight direction corresponds to the dip of the cross-polar antenna pattern and thus the polarization isolation of the system is overestimated. This has a direct effect on the estimation of the distortion matrix **D**, since the polarization isolation of the antenna is directly related to the values of d_1 and d_2.

The second effect is that due to differences between co-polar and cross-polar antenna patterns (see Fig.1), decorrelation occurs between M_{hv} and M_{hh} (or M_{vv}) even when S_{hv} is much smaller than the antenna limit (Moisseev, et al., 2000). This decorrelation is not taken into account by the point target calibration procedure.

3.3 Improvement of radar polarimetric calibration

The best approach to consider all these effects is to use the complete antenna pattern for polarimetric radar calibration as shown in (7). However, measurement of antenna patterns is usually very complicated and time-consuming. Thus, our approach will be to use a known extended target in order to improve polarimetric calibration.

A good example of the known distributed target is light rain measured with the radar pointing to the zenith (see Fig. 2). In this case light rain can be considered as an isotropic target with $Ldr = \left\langle |S_{hv}|^2 \right\rangle \Big/ \left\langle |S_{hh}|^2 \right\rangle$ close to zero.

In this case the radar polarization isolation is given by $1/Ldr$. And the correlation coefficient r_d between co- and cross-polar measurements gives directly the decorrelation due to differences in the antenna patterns.

Using light rain measurements the point target calibration can be adjusted to allow for distributed nature of atmospheric targets. This procedure can be divided into two steps:

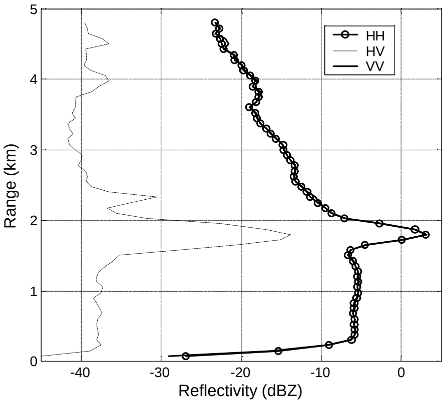

Fig. 2 The vertical profile of the light rain event

1. d_1 and d_2 coupling terms should be multiplied by $\sqrt{Ldr / r_a}$ where r_a is the antenna isolation determined from the point target measurements. Here $\sqrt{Ldr / r_a}$ is the ratio of the polarization isolations for extended and point targets.
2. the elements of the distortion matrix **D** which are proportional to d_1 or d_2 should be multiplied by the correlation coefficient r_d to take into account the decorrelation due to differences in the antenna patterns.

The resulting *Ldr* of the light rain after first step of calibration is shown in Fig. 3. And Fig. 4 shows the resulting *Ldr* after both steps. It can be seen that *Ldr* is reduced in rain and the *Ldr* values in the melting layer are almost not affected.

4. CONCLUSIONS

The problem of polarimetric radar calibration for distributed target measurements was discussed on the examples of *Zdr* and *Ldr* measurements. It was shown that *Zdr* is not very sensitive to the influence of the complete antenna pattern on the measurement and thus the point target polarimetric calibration can be used for the estimation of *Zdr*.

The *Ldr* measurements, on the contrary, are very sensitive to the influence of the complete antenna pattern. It was shown that by taking into account this influence the sensitivity of the radar for cross-polar measurements can be improved.

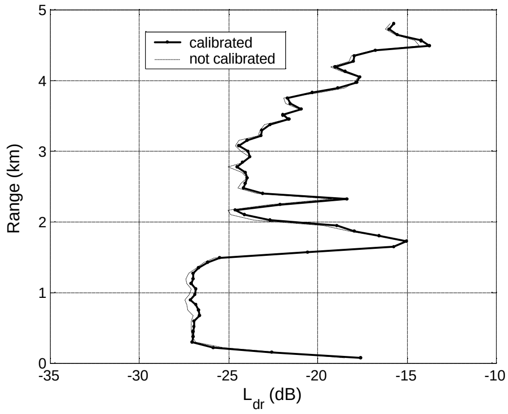

Fig. 3 *Ldr* before and after polarimetric calibration. There is only compensation for the difference between point and extended target polarization isolation.

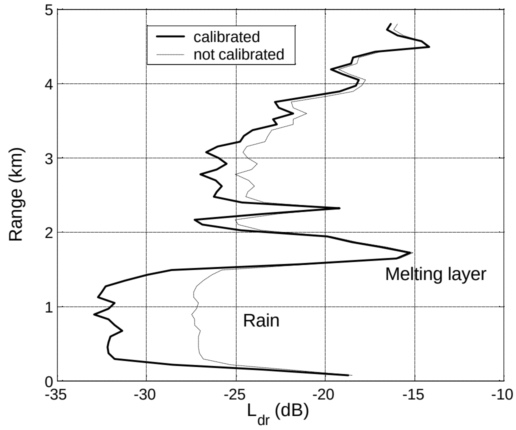

Fig. 4 *Ldr* before and after polarimetric calibration. For the calibration both extended target polarization isolation and compensation for the decorrelation between cross- and co-polar measurements due to the antenna patterns were used.

5. REFERENCES

Blanchard, A.J. and Jean, B.R., 1983: Antenna effects in depolarization measurements.

IEEE Tr. Geosci, Remote Sens., **21**, 113-117

Moisseev, D.N., Unal, C.M.H., Russchenberg, H.W.J. and Ligthart, L.P., 2000: The influence of the antenna pattern on cross polarization measurements of atmospheric targets.

Phys. Chem. Earth (B)., **25**, No. 10-12, 843-848

Ryzhkov, A.V., 2001: Interpretation of polarimetric covariance matrix for meteorological scatterers: Theoretical analysis.

*J. Atmos. Oceanic Technol., **18**, 315-328*

Sarabandi, K., Ulaby, F.T., and Tassoudji, M.A., 1990: Calibration of polarimetric radar system with good polarization isolation.

IEEE Trans. Geosci. Remote. Sens., **28**, 70-75

Unal, C.M.H., Niemeijer, R.J., van Sinttruyen, J.S. and Ligthart, L.P., 1994: Calibration of a polarimetric radar using a rotatable dihedral corner reflector.

IEEE Trans. Geosci. Remote. Sens., **32**, 837-845