EIPT-13. **Quality parameter for a weather radar antenna**

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1. Introduction

Radar polarization measurements in clouds and precipitation require a high quality antenna. To assess antenna's impact, laborious measurements of amplitudes and phases of the radiation pattern in the far field zone of an antenna are needed. For an S-band antennas such measurements require a special antenna range. Then, integration of the measured parameters over the whole pattern must be performed to obtain the integrated antenna impact on the polarimetric variables [1,2,3].

The antenna impact can be estimated from data collected in light rain (parameter ***β***, section 2). Results of measurements of ***β*** with the WSR-88D radar are presented in section 3. Computer simulation results are discussed in section 4.

2. Radar parameter *β* for assessing the antenna quality

The antenna radiation pattern matrix ***F*** is [6]

$$\boldsymbol{F} = \begin{bmatrix} F_{hh} & F_{hv} \\ F_{vh} & F_{vv} \end{bmatrix}. \quad (1)$$

The quality of the antenna is characterized by the ratio of the cross coupling terms F_{hv} and F_{vh} to the copolar terms F_{hh} and F_{vv}. For a well designed antenna, the level ***L*** of cross-polarization coupling must be smaller than -40 dB [4,5,6], i.e.,

$$\boldsymbol{L} = \frac{\int |F_{hv}|^2 d\Omega}{\int |F_{hh}|^2 d\Omega} \approx \frac{\int |F_{vh}|^2 d\Omega}{\int |F_{hh}|^2 d\Omega} < -40 \text{ dB} \quad (2)$$

To obtain a parameter, which estimates ***L***, the **Linear Depolarization Ratio** (**LDR**) radar mode can be used. In the LDR mode, radar transmits a wave at one polarization, say horizontal, and receives both polarizations, i.e., horizontal and vertical. Two radar moments should be measured in the LDR mode: the returned power at H-polarization (P_h) and the correlation function R_{hv} between voltages at the H- and V-polarizations:

$$P_h = < \int |\delta V_h|^2 d\Omega >, \qquad R_{hv} = < \int \delta V_h^* \delta V_v d\Omega >, \quad (3)$$

where δV_h and δV_v are received voltages at H- and V-polarizations from a single scatterer and integration is performed over the antenna pattern. For measurements in light rain, it can be shown that

$$\frac{R_{hv}}{P_h} \cong \beta[\exp(j\varepsilon) + \exp(j\Phi_{DP} + j\chi)] + \rho_{xh} L_{dr}^{1/2} \exp(j\Phi_{DP}/2 + j\omega), \quad (4)$$

where L_{dr} is the intrinsic linear depolarization ratio in power units, ρ_{xh} is the cross-polar correlation coefficient, Φ_{DP} is the differential phase, ε, χ, ω are appropriate phases, and

$$\beta = \frac{\int |F_{hh}|^3 |F_{hv}| d\Omega}{\int |F_{hh}|^4 d\Omega} \cong \frac{\int |F_{hv}| d\Omega}{\int |F_{hh}| d\Omega} \cong L^{\frac{1}{2}}. \quad (5)$$

Thus, the parameter ***β*** can be used to estimate the integrated cross-coupling ***L*** (2).

Radar data and signal simulations show that the last term in (4) prevails because of strong positive bias in ρ_{xh}. Therefore, the module of the first term in (4) is smaller than the module of its left part, i.e.,

$$\boldsymbol{\beta} < \left|\frac{R_{hv}}{P_h}\right|. \quad (6)$$

To obtain the integrated parameter ***β***, radar observations in light rain can be utilized. **For precise measurements of the polarization parameters in the SHV mode (Z_{DR} and ρ_{hv}), *β* should be smaller than -20 dB.** For instance, to measure Z_{DR} with an accuracy of 0.2 dB, the integrated cross-coupling terms should be of order of -22 dB and ***L*** should be about -42 dB [4,5].

3. Estimating *β* from radar data

To obtain ***β*** from radar data, radar should be in the LDR mode and the measurements have to be taken in drizzle, where small droplets have almost spherical shape. The WSR-88D KOUN (Norman, OK) had the capability to operate in the LDR mode in until about 2009. Data collected in that mode are used to estimate $|R_{hv}/P_h|$ and some results are presented in the figures below.

Case 1. 20 January 2007:

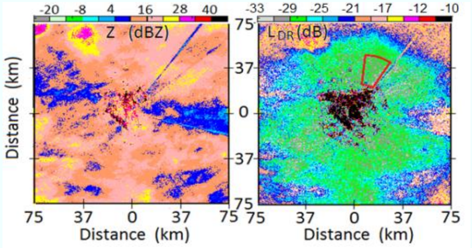

Fig. 1. Reflectivity (left panel) and L_{DR} (right panel) fields collected at 1757 UTC and elevation angle of 0.5 deg. Analysis area of drizzle is shown with the red sector.
$L_{DR} = 10\log(L_{dr})$

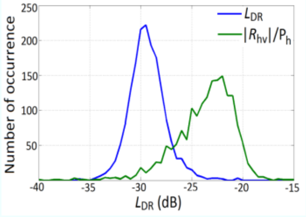

Fig. 2. Distributions of L_{DR} (the blue curve) and $|R_{hv}/P_h|$ (the green curve) for the data inside the red sector in Fig. 1. The mean $|R_{hv}/P_h|$ is -22.7 dB, so ***β ≤ -22.7 dB*** according to (6).

Case 2. 26 June 2007:

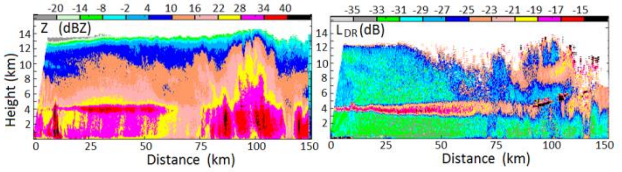

Fig. 3. Vertical cross section of reflectivity (left panel) and L_{DR} (right panel) collected at 1205 UTC and azimuth of 209 deg.

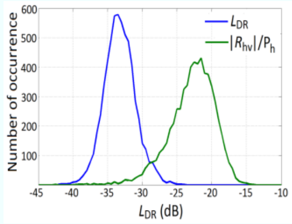

Fig. 4. Distributions of L_{DR} (the blue curve) and $|R_{hv}/P_h|$ (the green curve) for the data within distances from 20 to 55 km and below the melting layer in Fig. 3. The mean $|R_{hv}/P_h|$ is -22.3 dB, so ***β ≤ -22.3 dB****.*

The analysis of radar data shows that *β* is about -22 dB for the WSR-88D's antenna and $L \cong \beta^2$ is about – 45 dB; this enables precise polarization measurements in the SHV mode.

4. Estimating *β* from computer simulations

Eq. (4) allows estimating ***β*** using signal simulations. Simulating radar signals with given input $\boldsymbol{L}_{dr}$, Φ_{DP}, and ρ_{xh} is straightforward. To simulate the antenna cross coupling, additional terms have been introduced to the simulations with ***β*** as an input parameter. These terms have been derived from the antenna radiation pattern (1). The simulations have been performed for an array of the input parameters. For each set of input parameters, 20,000 simulations have been made to obtain the distributions of $\boldsymbol{L}_{dr}$ and $|R_{hv}/P_h|$.

The parameter ***β*** has been estimated by matching the simulated distributions with the radar ones. The example in Fig. 5 is for data collected in Case 2 (Fig. 4). A good match is achieved for ***β*** = - 23.5 dB, which is close to ***β*** = -22.3 dB estimated from radar data (see Fig. 4). So the simulations suggest that β^2 **< - 45 dB** for the WSR-88D's antenna.

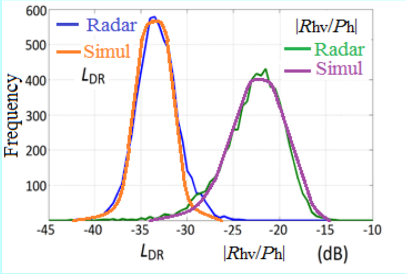

Fig. 5. Distributions of L_{DR} from radar data in Fig. 4 (the blue curve) and results of signal simulations (the brown curve). Distributions of $|R_{hv}/P_h|$ from radar data (the green curve in Fig. 4) and results of the simulations (the magenta curve).

5. Conclusions

- Precise polarization measurements require the cross-polar antenna coupling to be lower than -40 dB. A parameter β^2 to asses the coupling from radar data is derived in section 2 by measuring the powers and correlation function of returned signals in the LDR mode. For the WSR-88D's antenna, the data analysis and simulation results show that β^2 is about -45 dB; this allows measurements of ZDR with an accuracy of 0.1 dB.
- The described technique for the WSR-88D's antenna can be applied to phased array antennas. This however requires the LDR mode capability on the phased array weather radar.

References

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