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Theoretical analysis of polarization characteristics for planar and cylindrical phased array radars

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Abstract

In this work, antenna polarization characteristics of the two array configurations (i.e., planar and cylindrical structures) are analyzed and compared, and polarimetric parameter (e.g., differential reflectivity) bias correction techniques for the two antennas are presented. The cross-polarization of one polarization at mainbeam direction can be calculated and corrected by adjusting the amplitude and phase of the other polarization. In the case of cylindrical polarimetric phased array radar (CPPAR), the beam is formed at the bisector of the cylindrical sector and cross-polarizations caused by opposing elements in azimuth cancel each other, yielding very low cross-polarization level. Copolar and cross-polar patterns of planar polarimetric phased array radar (PPPAR) and that CPPAR are compared to reveal their advantages and disadvantages. In addition, to quantify their respective performance, effects of antenna element separation, and errors in element placement and element failure are studied.

Introductions

Polarimetry and phased array are two advanced radar technologies that have received much attention and are making contributions in the weather community. It is, however, a big challenge to combine the two technologies into one system for future Multi-mission Phased Array Radar (MPAR). The challenge comes from the fact that polarization base changes as radar beam electronically scan off broadside of a planar array antenna. For planar polarimetric phased array radar (PPPAR), horizontally (H) and vertically (V) polarized wave fields are not perpendicular when the beam scans away from broadside. That is H-pol and V-pol fields are coupled, which causes high cross-polarization for planar structure.

To preserve the H, V bases, a cylindrical array configuration has been recently proposed as a candidate for MPAR (Zhang et al. 2011). CPPAR has the characteristics of the polarization purity and scan invariant beam in azimuth. The horizontal and vertical polarized wave fields will be orthogonal in all beam directions. The CPPAR would essentially eliminate the beam-to-beam calibration that is required for a PPPAR . In azimuth, the mainlobe is always at broadside and scan is achieved by shifting the column of active elements. A very low cross-polarization level is achieved (Lei at al. 2011).

Comparison between PPPAR and CPPAR

Both antennas are to mimic WSR-88D; Element separation is 0.5λ; uniform weighting is used; simulation step is 0.2 degree.

1) PPPAR main beam points at $(\theta,\phi)=(70°,45°)$

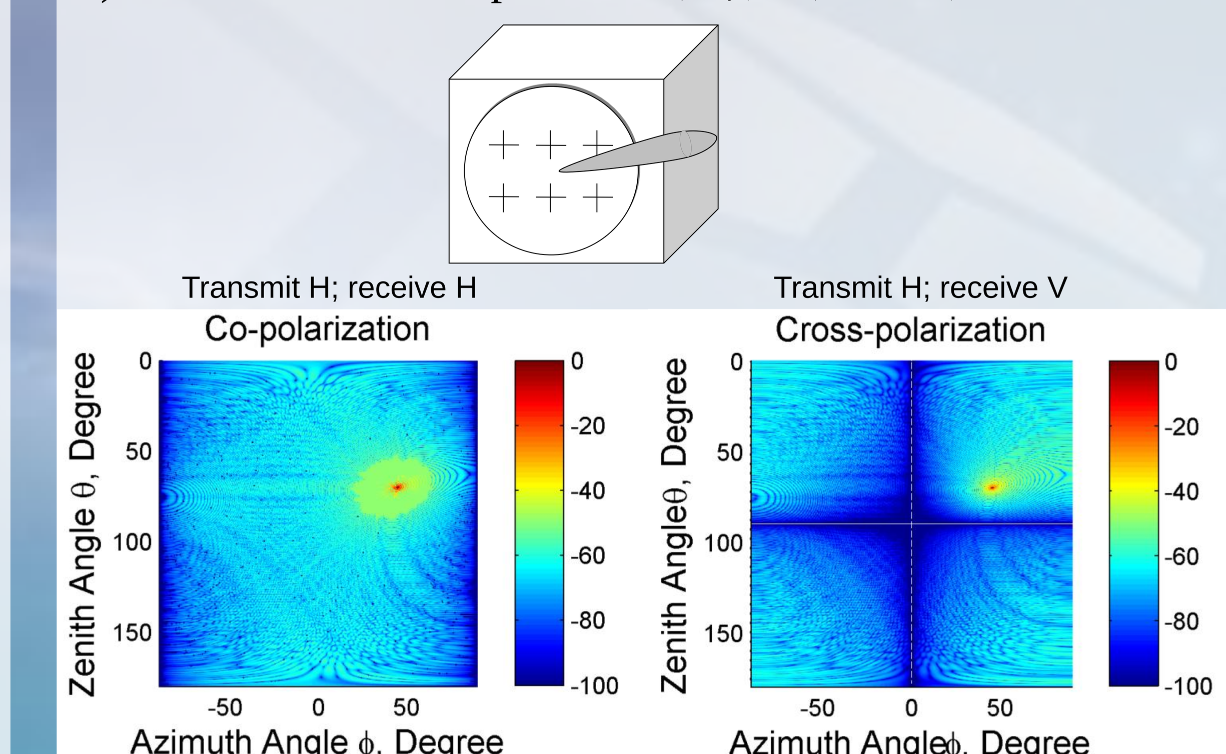

Fig.1 Planar PPAR, co-polar and cross-polar patterns
Cross-polar pattern peak is -9.3dB.

2) CPPAR main beam points at $(\theta,\phi)=(70°,0°)$

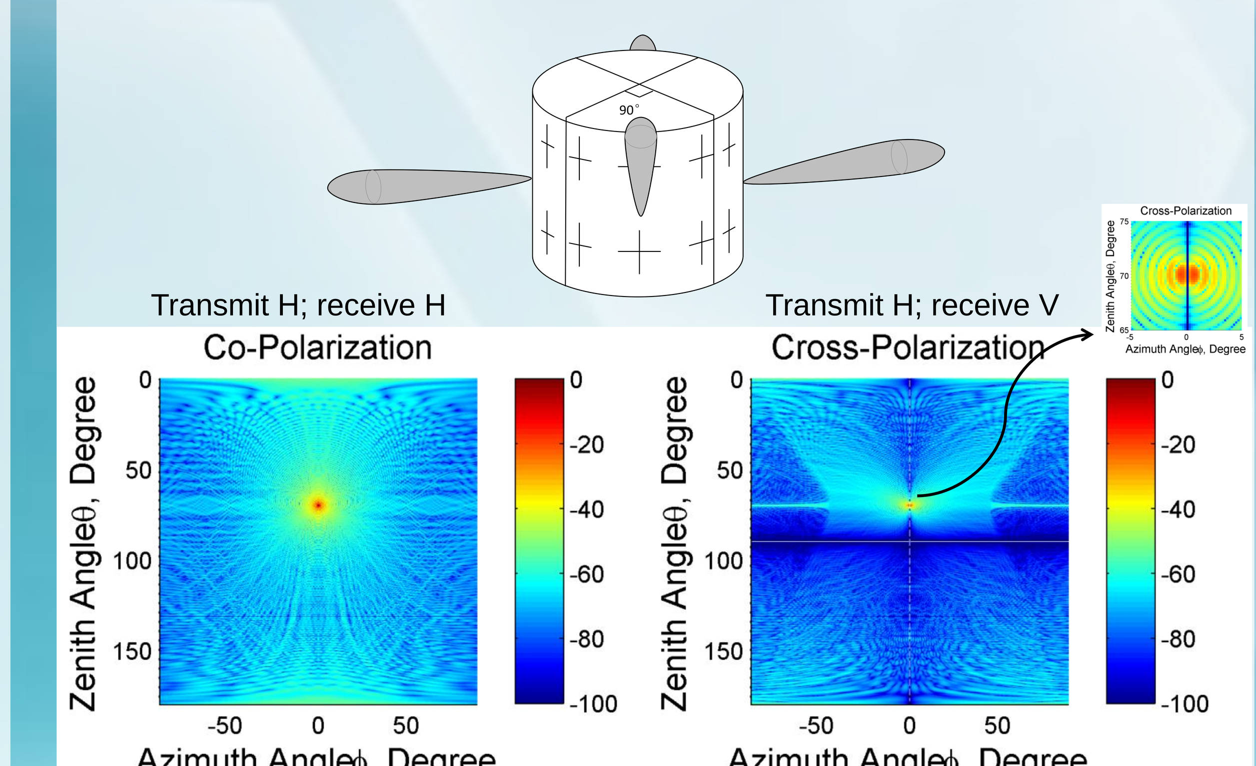

Fig.2 Cylindrical PPAR, co-polar and cross-polar patterns
Cross-polar pattern peak is -20.0dB

The pattern comparison shows that the cylindrical array has much lower cross-polar pattern peak than the planar array, which allows more accurate measurement of weather radar parameters.

Cross-pol reduction through calibration

By applying the correction matrix at each beam pointing angle, the cross-pol of PPPAR can be significantly reduced (Zhang et al. 2009). The procedure is following:

$$\vec{E}_{\mathrm{i}}=\mathbf{P}\vec{E}_{\mathrm{t}}=\begin{bmatrix}\cos\phi & 0\\ -\cos\theta\sin\phi & \sin\theta\end{bmatrix}\begin{bmatrix}E_{\mathbf{th}}^{(c)}\\ \Delta E_{\mathbf{tv}}^{(c)}\end{bmatrix}=\begin{bmatrix}\cos\phi E_{\mathbf{th}}^{(c)}\\ -\cos\theta\sin\phi E_{\mathbf{th}}^{(c)}+\sin\theta\Delta E_{\mathbf{tv}}^{(c)}\end{bmatrix} \quad (1)$$

At the main beam direction:

$$\vec{E}_{\mathrm{i}}=\begin{bmatrix}1\\ 0\end{bmatrix} \quad (2)$$

Combine (1) and (2), we have the new amplitude:

$$\begin{cases} E_{\mathbf{th}}^{(\mathbf{c})}=\dfrac{1}{\cos\phi_o}\\ \Delta E_{\mathbf{tv}}^{(\mathbf{c})}=\dfrac{\cos\theta_o\sin\phi_o}{\sin\theta_o\cos\phi_o}\end{cases} \quad (3)$$

Therefore, the amplitudes used in the cross-polarization pattern calculations are Eq. (5):

$$F=\sum_{n=1}^{N}A(\theta,\phi)\exp(j\varphi_n) \quad (4)$$

where $$A(\theta,\phi)=-\cos\theta\sin\phi\left(\frac{1}{\cos\phi_o}\right)+\sin\theta\left(\frac{\cos\theta_o\sin\phi_o}{\sin\theta_o\cos\phi_o}\right) \quad (5)$$

Before

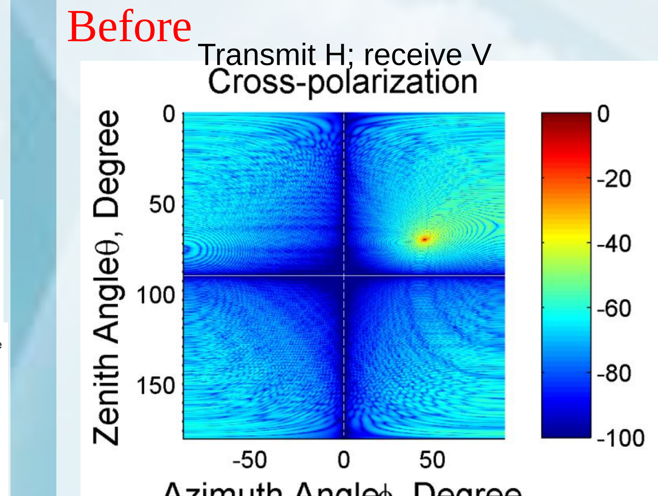

Fig. 3a cross-pol pattern of planar array before adjustment. Cross-pol peak is -9.3dB.

After

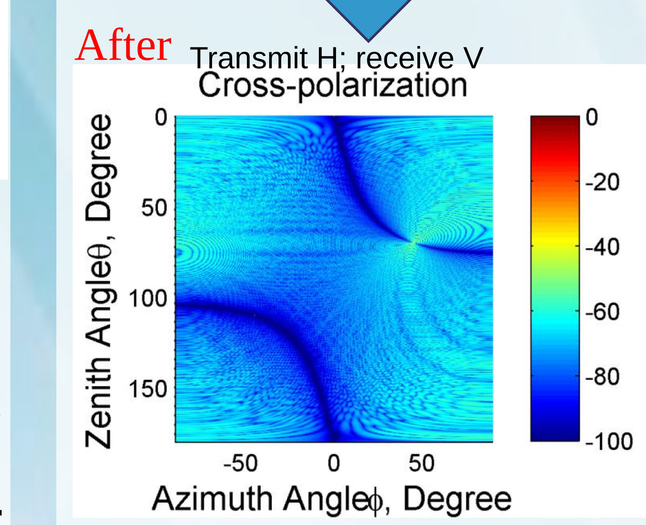

Fig. 3b cross-pol pattern of planar array after adjustment. Cross-pol peak is -43.6dB.

Cross-pol of CPPAR can also be corrected at the main beam direction, which is more complicated than the PPPAR. However, because -20dB is good enough for weather applications, the correction is unnecessary.

Error effects (element failure and positioning error)

1) Element failure: element failure increases the sidelobe level but has no effect on the cross-pol peak.

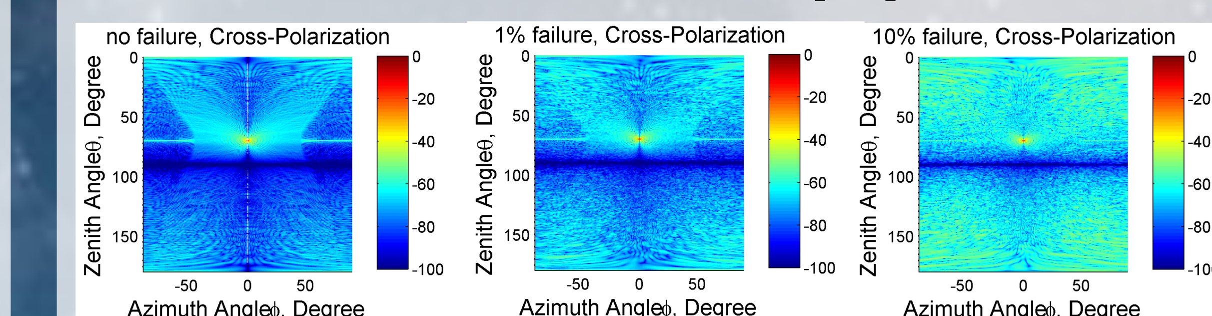

Fig.4 no element failure, 1% failure, and 10% failure.

2) Mechanical positioning error: positioning error increases the sidelobe level but has no effect on the cross-pol peak.

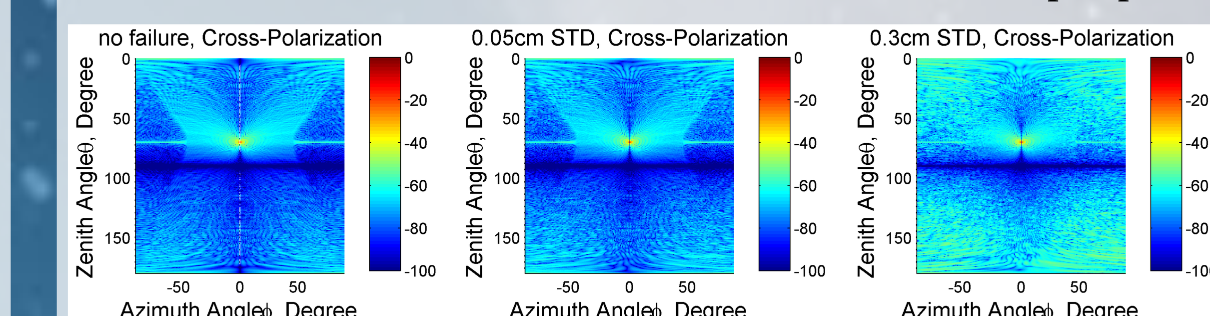

Fig.5 accurate, 0.0045λ std, and 0.027λ std.

Summary

1) The cross-pol level of cylindrical array is much lower than that of planar array.
2) The high cross-pol of planar array can be adjusted to very low level by applying correction matrix. The other way to reduce cross-pol effect is to correct the polarimetric parameters.
3) The cylindrical cross-pol level is so low that adjustment is not needed if the elevation angle is less than 20 degree.
4) Element failure increases the sidelobe level but has no effect on the cross-pol peak.
5) Mechanical positioning error increases the sidelobe level but has no effect on the cross-pol peak.

References

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