Effects of Antenna Patterns on Bias in Differential Reflectivity

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Coupling of H and V fields

- Coupling between the horizontally and vertically polarized fields
  - Can be caused by the medium
    - During propagation
    - Upon backscattering
  - Can originate within the radar system
    - Coupling through the antenna is an order of magnitude larger than coupling through the rest of the radar system

Effects of Coupling

- Simultaneous transmission and reception of H and V polarized fields (Pol WSR-88D):
  - Coupling can cause large biases in differential reflectivity (and other polarimetric variables)
- Alternate transmission and reception of H and V polarized fields:
  - The effects on polarimetric variables are generally negligible

Bias in ZDR – SHV mode

- The bias in Z_{DR} imposes the most stringent requirement on the antenna system
- Cross-polar voltage pattern and copolar voltage pattern determine the bias

  – Cross-polar voltage pattern: $(g_{hv})^{1/2} f_{hv}(\theta,\phi)$

  – Copolar voltage pattern: $(g_{hh})^{1/2} f_{hh}(\Omega)$

  solid angle: $\Omega=(\theta,\phi)$

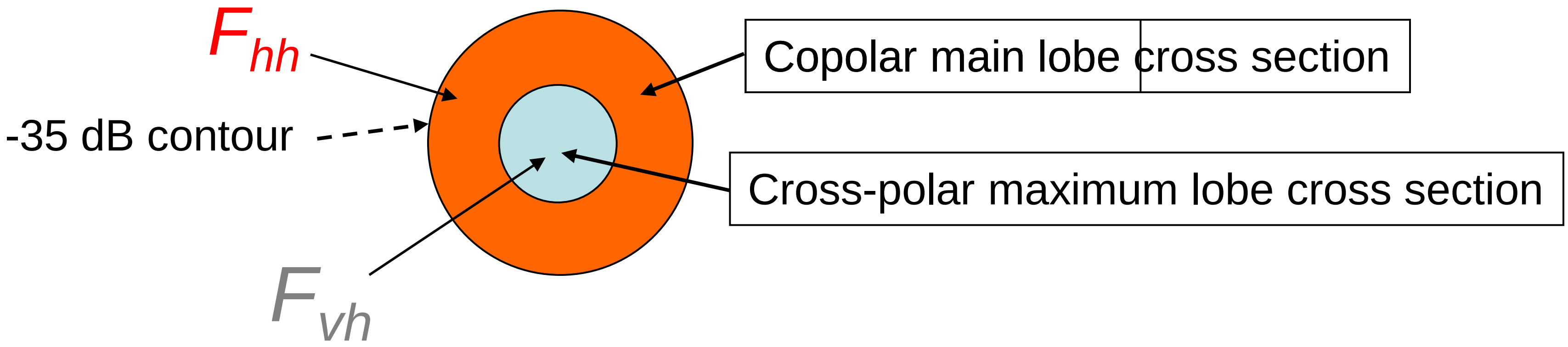
Bias in ZDR – SHV mode

- First and Second order terms in integrals of $(g_{hv})^{1/2} f_{hv}(\theta,\phi)$ can be significant contributors. Integrals are significant within the main lobe
  - First order integral term: $$\frac{\sqrt{g_{hv}}\int_{\Omega} f_{hv}(\Omega)\, f_{hh}^{3}(\Omega)\,d\Omega}{\sqrt{g_{hh}}\int_{\Omega} f_{hh}^{4}(\Omega)\,d\Omega}$$
  - Second order integral term: $$\frac{g_{hv}\int_{\Omega} \left| f_{hv}(\Omega)\right|^{2} f_{hh}^{2}(\Omega)\,d\Omega}{g_{hh}\int_{\Omega} f_{hh}^{4}(\Omega)\,d\Omega}$$

Two Antenna Pattern Types

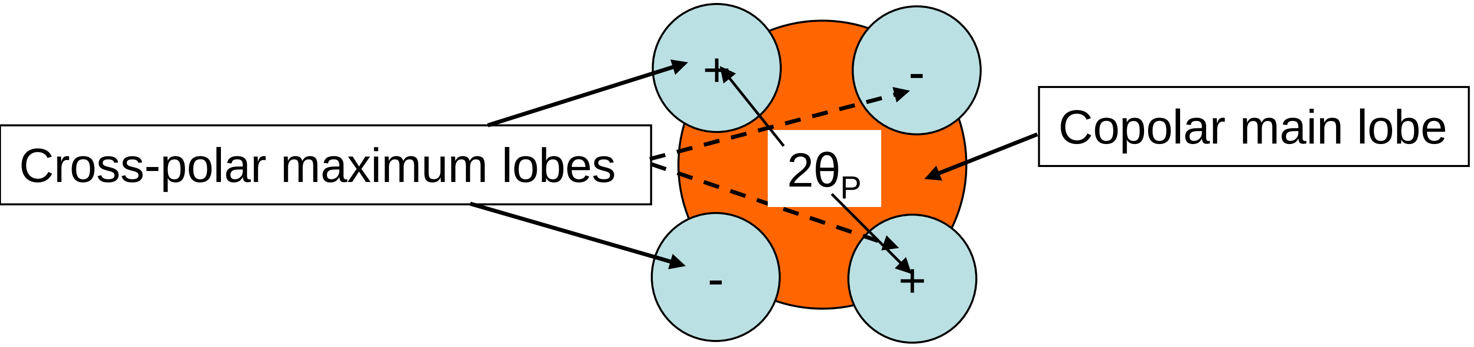
1) SINGLE CROSS-POLAR MAIN LOBE

Principal cross-polar LOBE coaxial with the copolar beam

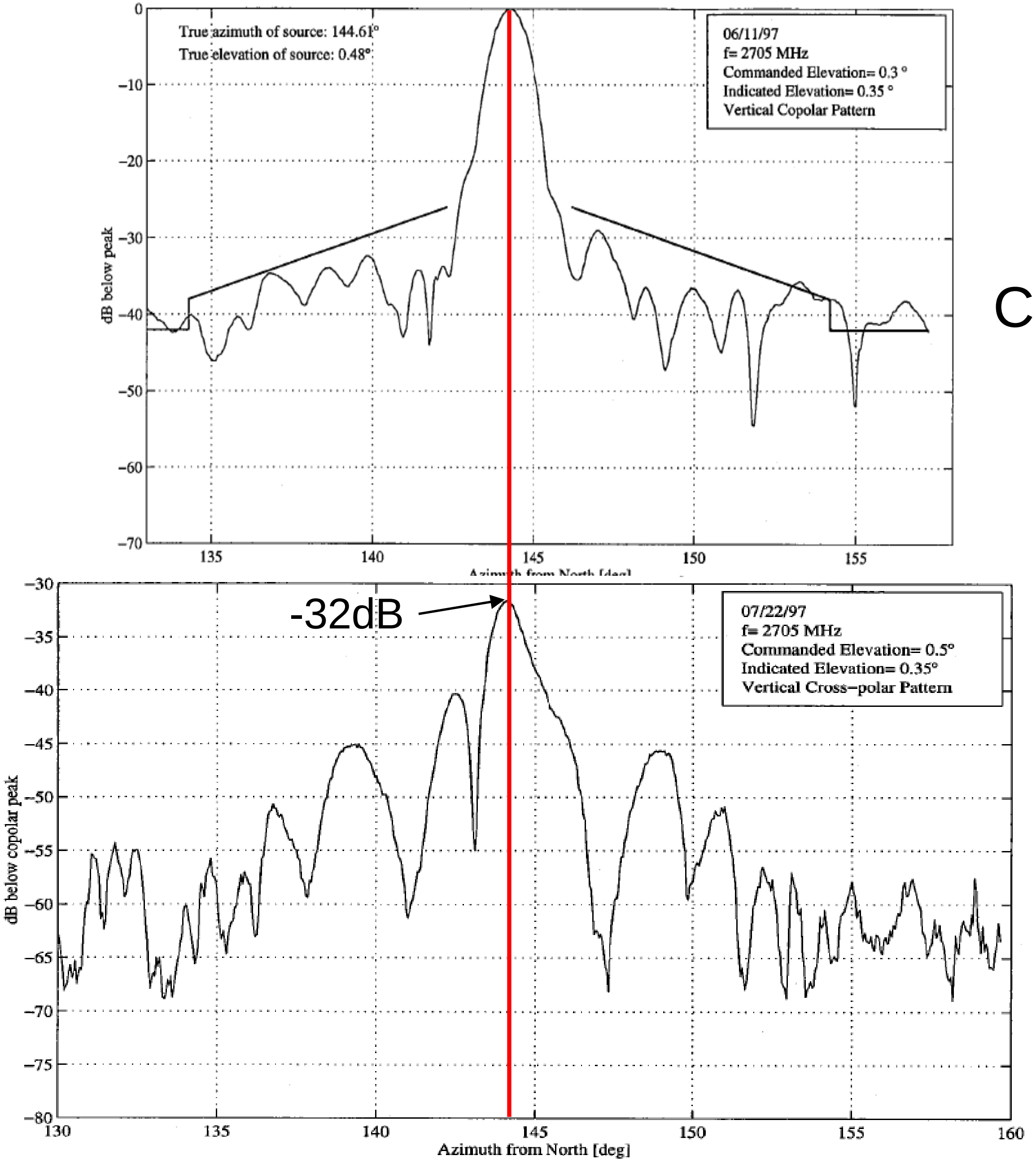


(2) MULTIPLE CROSS-POLAR MAIN LOBES:

(ALTERNATING PHASES)



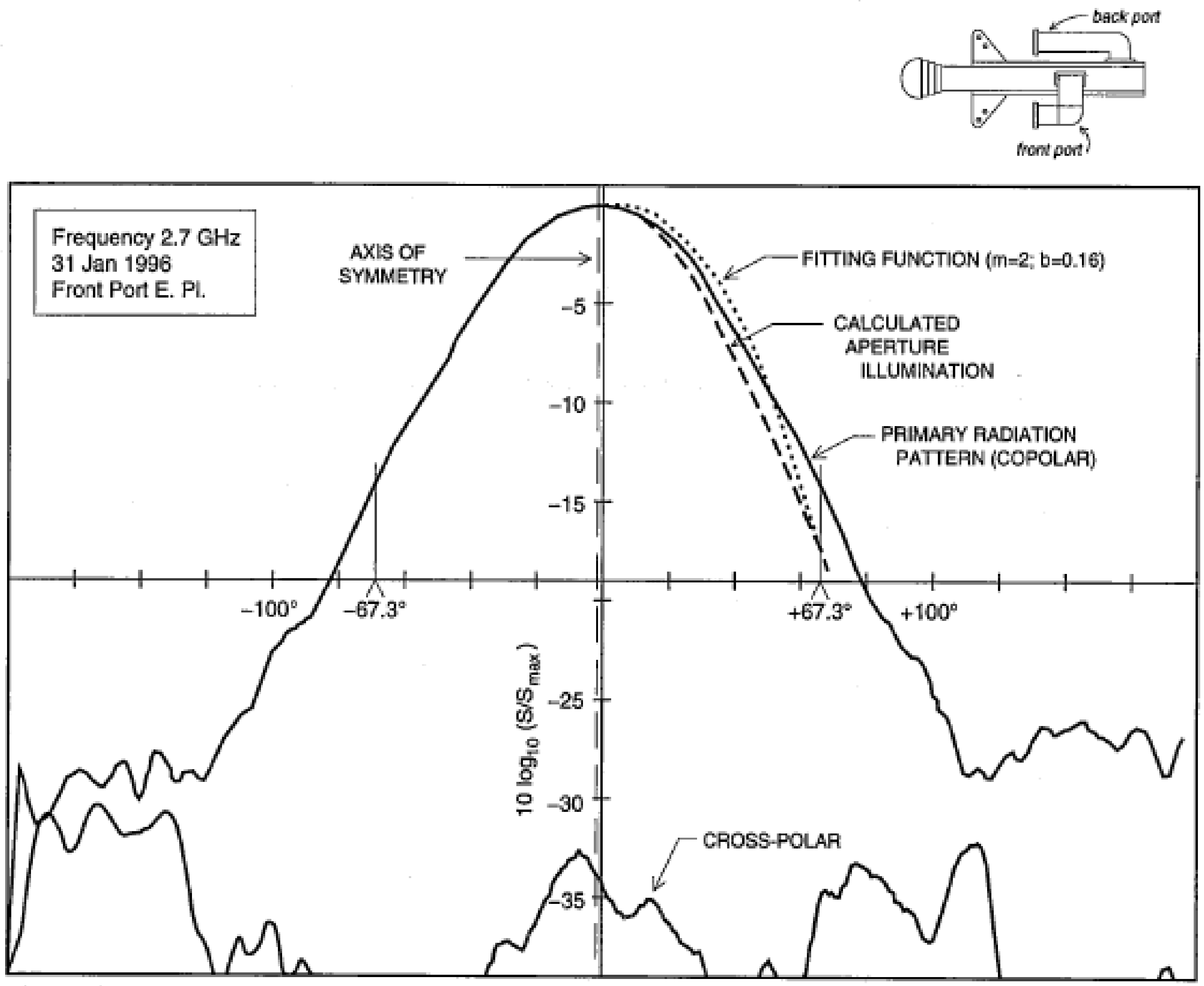
KOUN (WSR-88D)



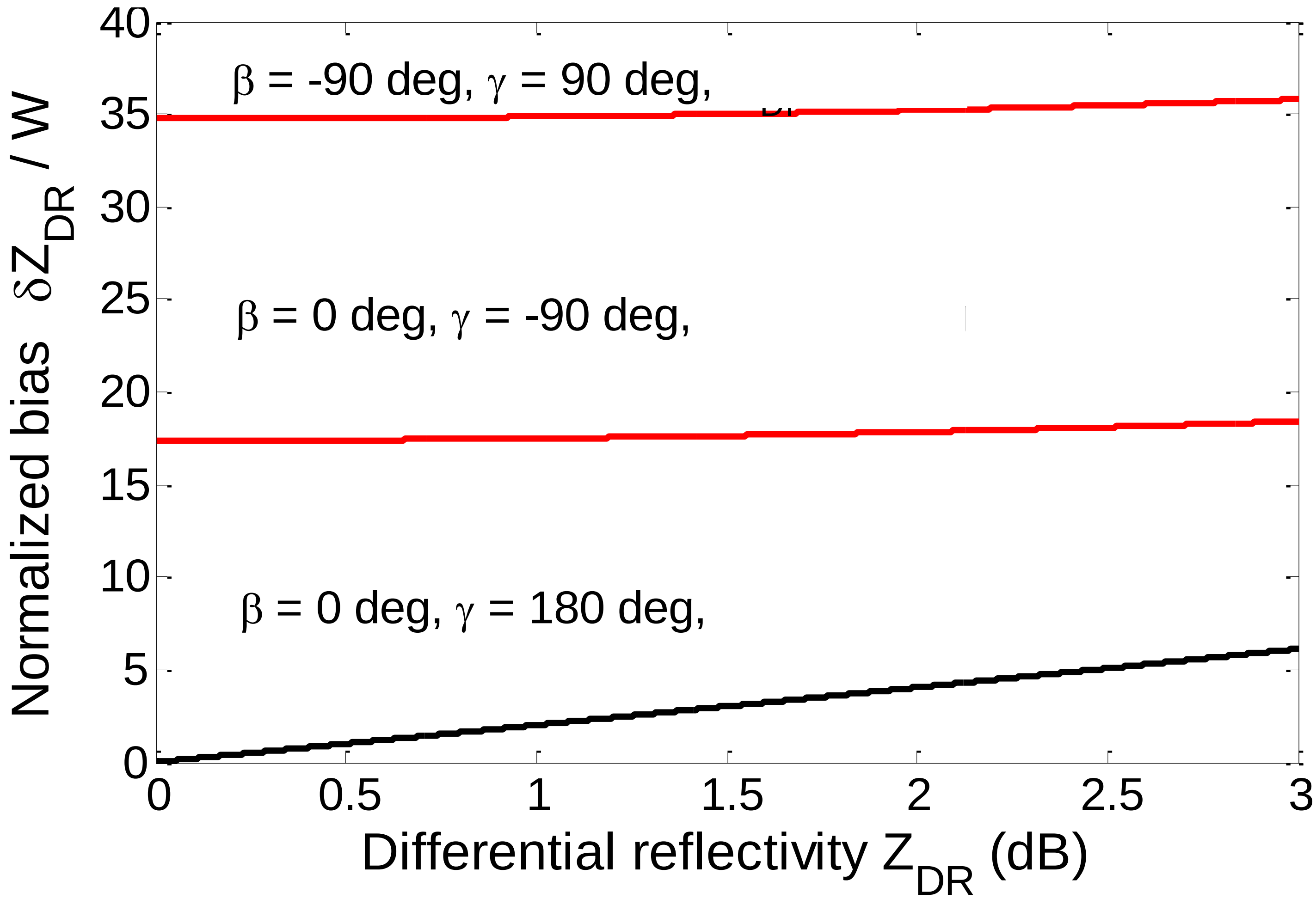
Copolar pattern $(f_{hh})^2$

Cross-polar pattern $(g_{vh}/g_{hh})|f_{vh}|^2$

Copolar and Cross-polar patterns of the feed horn (KOUN)



NORMALIZED BIAS DUE TO COAXIAL CROSS-POLAR AND COPOLAR BEAMS (SHV mode)



$$W_{hv} = W_{vh} \equiv W = \int F_{hh}^3 \,|\, F_{hv} \,| d\Omega \,/ \int F_{hh}^4 d\Omega$$

β=Transmit H, V phase difference;
γ=cross-, co-polar phase difference

For on-axis cross-polar Gaussian shape patterns:

$$W(SHV) = \frac{4\theta_{1x}^2}{\theta_1^2 + 3\theta_{1x}^2} \cdot \frac{g_{hv}^{1/2}}{g_{hh}^{1/2}}$$

Beamwidths: Copolar = θ_1; Cross pol = θ_{1x};

Gains: Copolar = g_{hh}; Cross pol = g_{hv}

For equal beamwidths, $W = (g_{hv}/g_{hh})^{1/2}$

On the KOUN, 10log(g_{hv}/g_{hh}) = -32 dB; or $W \approx 0.025$.

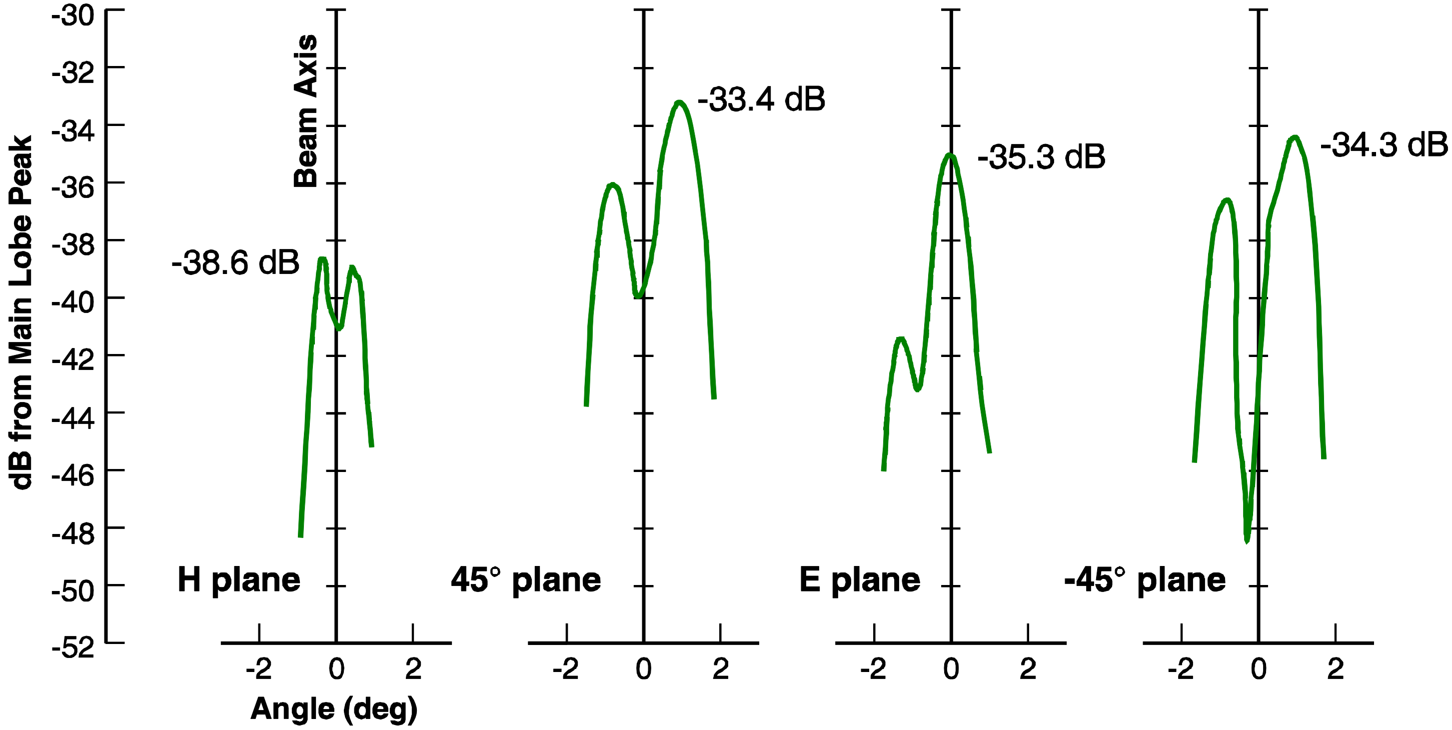
Thus the bounds on bias δZ_{DR} are:

Upper bound: $\delta Z_{DR} < 0.9$ dB

Intermediate bound: $\delta Z_{DR} < \pm 0.4$ dB (if $\beta = 0^o$)

Lower bound: $\delta Z_{DR} < \pm 0.05 Z_{DR}$ (if $\beta = 0$, & $\gamma = \pi$)

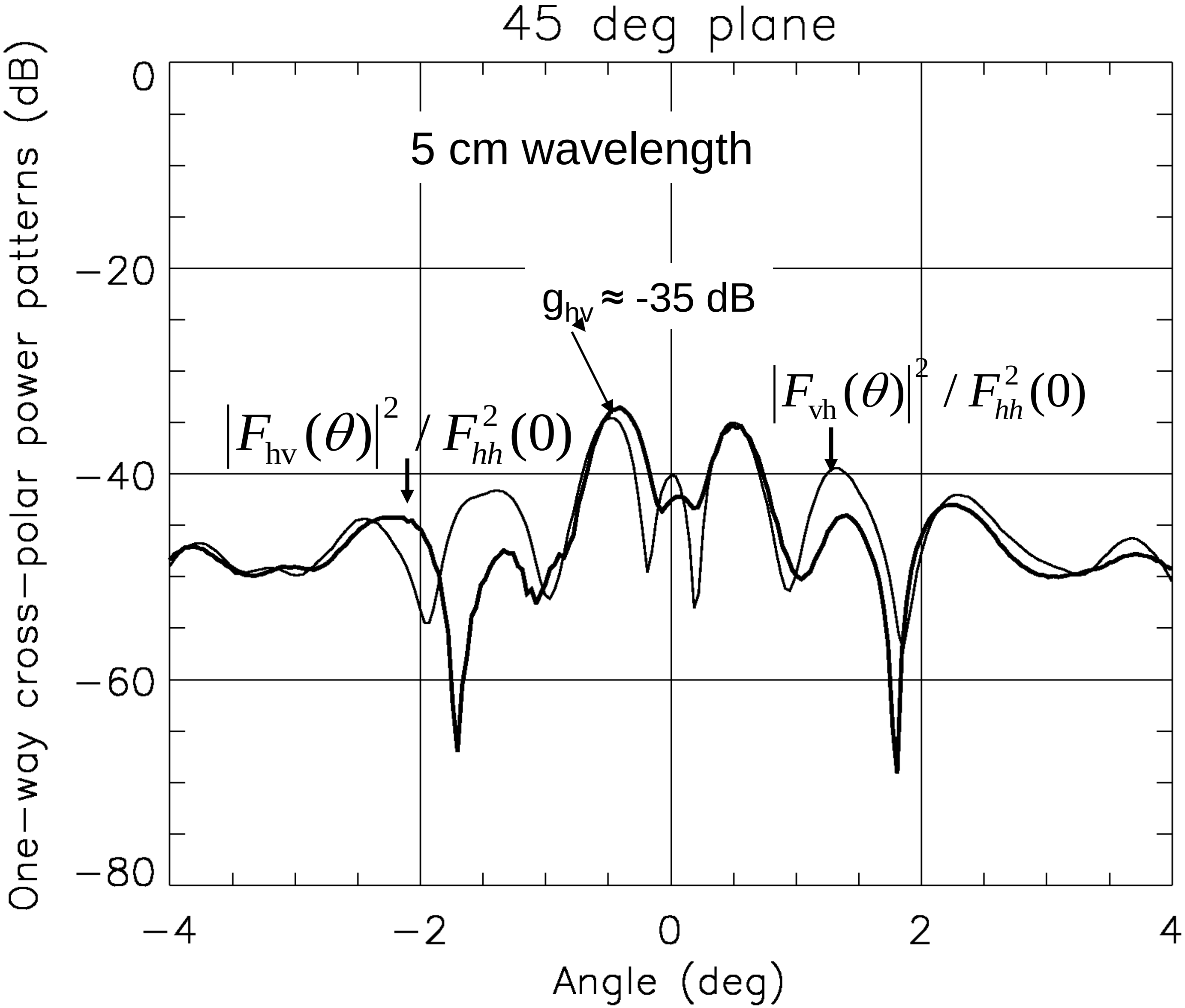
1) Cross-polar 10-cm $|F_{vh}|^2$ patterns for the upgraded WSR-88D antenna (Measurements made at a different site)



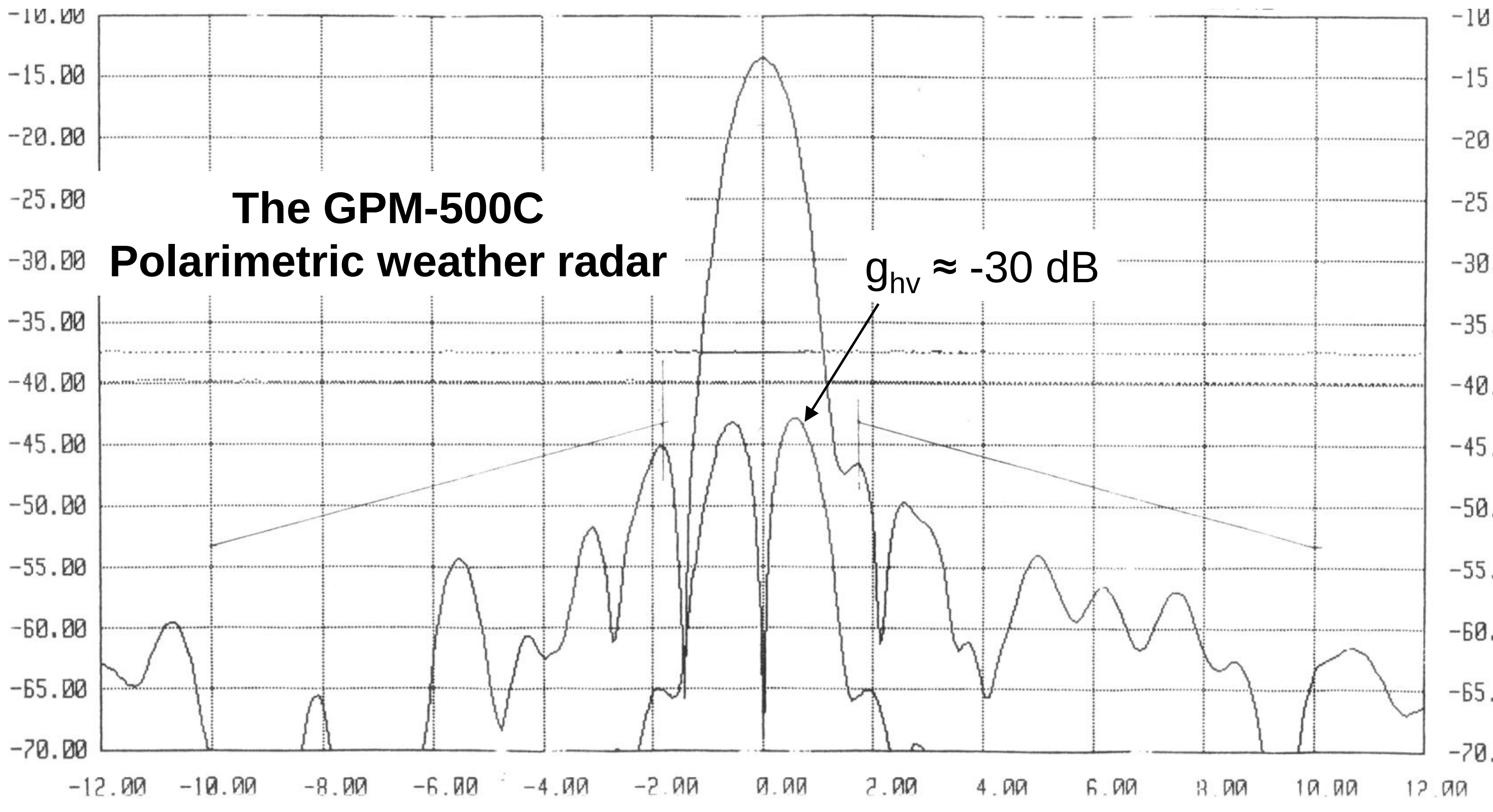
On-axis cross-polar gain: $g_{vh}(0) \approx -41$ dB

Median Cross-polar peak gain: $g_{vh}(\text{peak}) \approx -35$ dB

2) Cross-polar patterns along the 45 deg plane for OU PRIME



3) Copolar & cross-polar patterns for offset reflector (λ =5 cm)

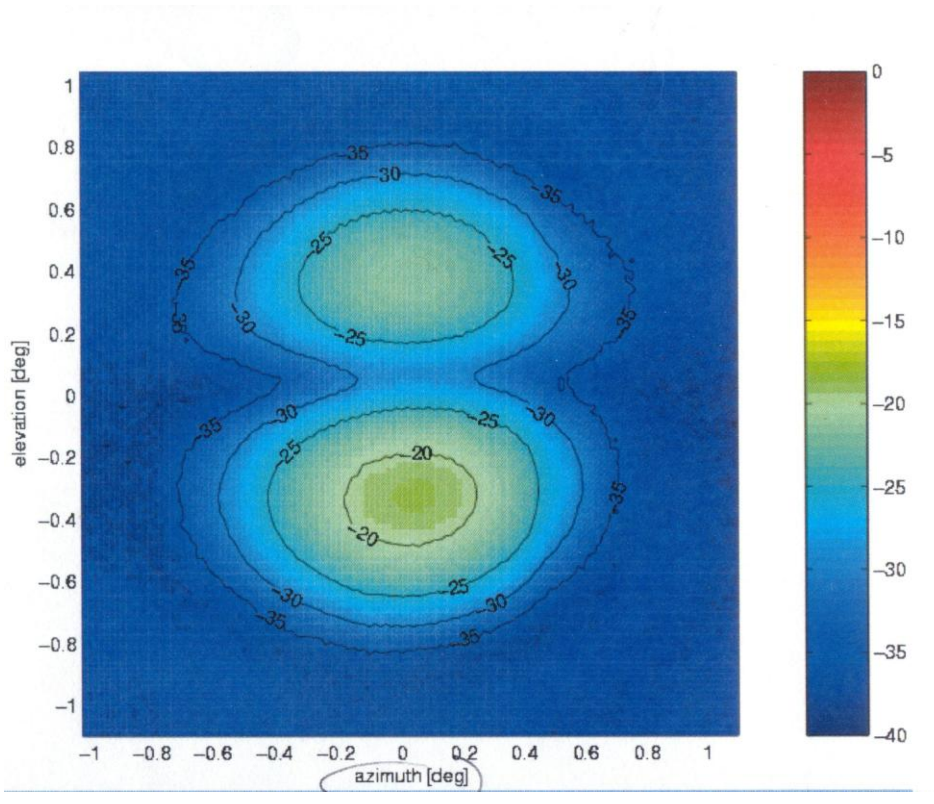


Compliments of Renzo Bechini,
Weather Operations Center, ERSA Friuli VeneziaGiulia-CSA

Cross-Polar pattern for the Swiss Polarimetric Imaging Radiometer (Offset reflector)

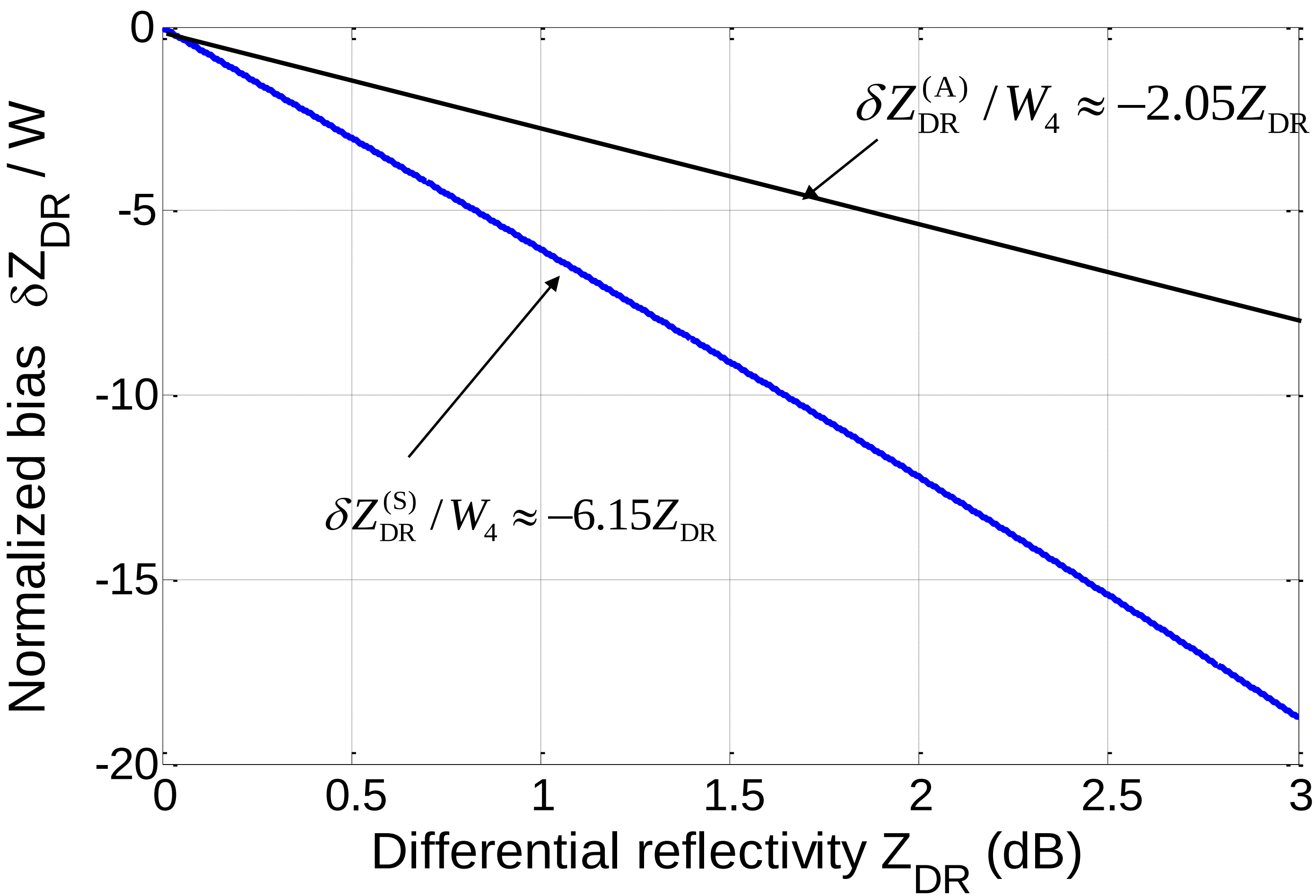
Offset parabola
λ =3 mm

Cross-polar peak:
= -18 dB



Adapted from Durić et al., (2008) IEEE Trans. Geosci. & Remote Sensing

Bias for a 4-lobed Cross-polar Pattern



$$W \equiv W_4 = \frac{\int F_{hh}^2 \, |F_{hv}|^2 d\Omega}{\int F_{hh}^4 d\Omega} = 4 \frac{2 g_{hv} \theta_{1x}^2}{g_{hh} (\theta_{1x}^2 + \theta_1^2)} \exp\left[-\frac{4\theta_p^2 \ln(2)}{(\theta_1^2 + \theta_{1x}^2)} \right]$$

For the condition:

$$\theta_1 \approx \theta_{1x} \approx \theta_p$$

$\mathbf{W_4 \approx g_{hv}/g_{hh}}$

Sample calculations of the bias weighting factor W_4 for the three antenna patterns

	peak gain g_{hv}/g_{hh}	bias weighting factor W_4	Bias(SHV) δZ_{DR} (dB)
1) OU PRIME:	-35 dB	$\approx 3x10^{-4}$	$2x10^{-3}Z_{DR}$
2) GPM-500C:	-30 dB	$W_2 \approx 5x10^{-4}$	$3x10^{-3}Z_{DR}$
3) WSR-88D:	-35 dB	$\approx 3x10^{-4}$	$2x10^{-3}Z_{DR}$

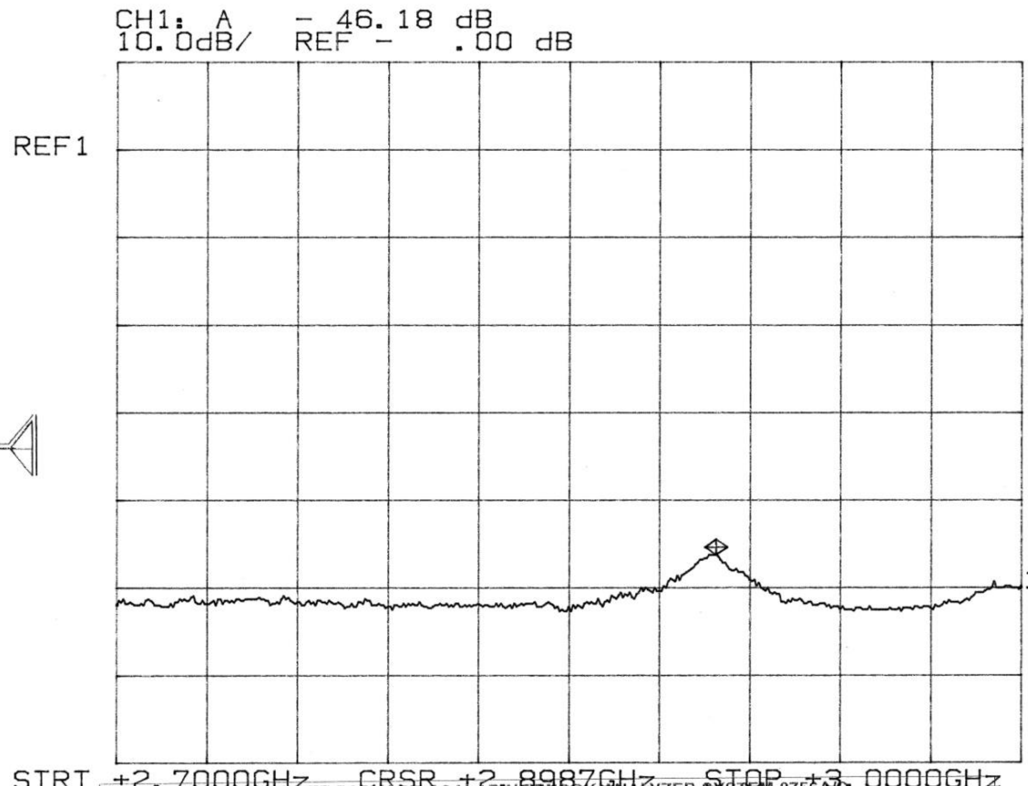
In all cases the computed ZDR bias is below 0.1 dB
Other factors and imperfections could have more significant influence on the bias?

Conclusions

- Z_{DR} bias should be < $0.1Z_{DR}$ for rain rate error < 20 %
- Bias is most sensitive to Coaxial Cross-polar radiation
- Large coaxial cross-polar radiation should not be caused by parabolic dish antennas
- The intrinsic cross-polar pattern of center feed reflectors is a Quad of principal lobes
- Pattern with a Quad of lobes causes insignificant bias
- Cross-polar pattern of the preproduction WSR-88D has Quad cross-polar lobes that are at about 35 dB below the main lobe peak; hence bias cause by these should be less than 0.1 dB.
- If the gross-polar gain at beam center of a quad pattern is < - 40 dB compared to antenna gain the worst bias in Z_{DR} is <0.14 dB

First Article Port to Port Isolation

Test Conditions DUAL POL FEED

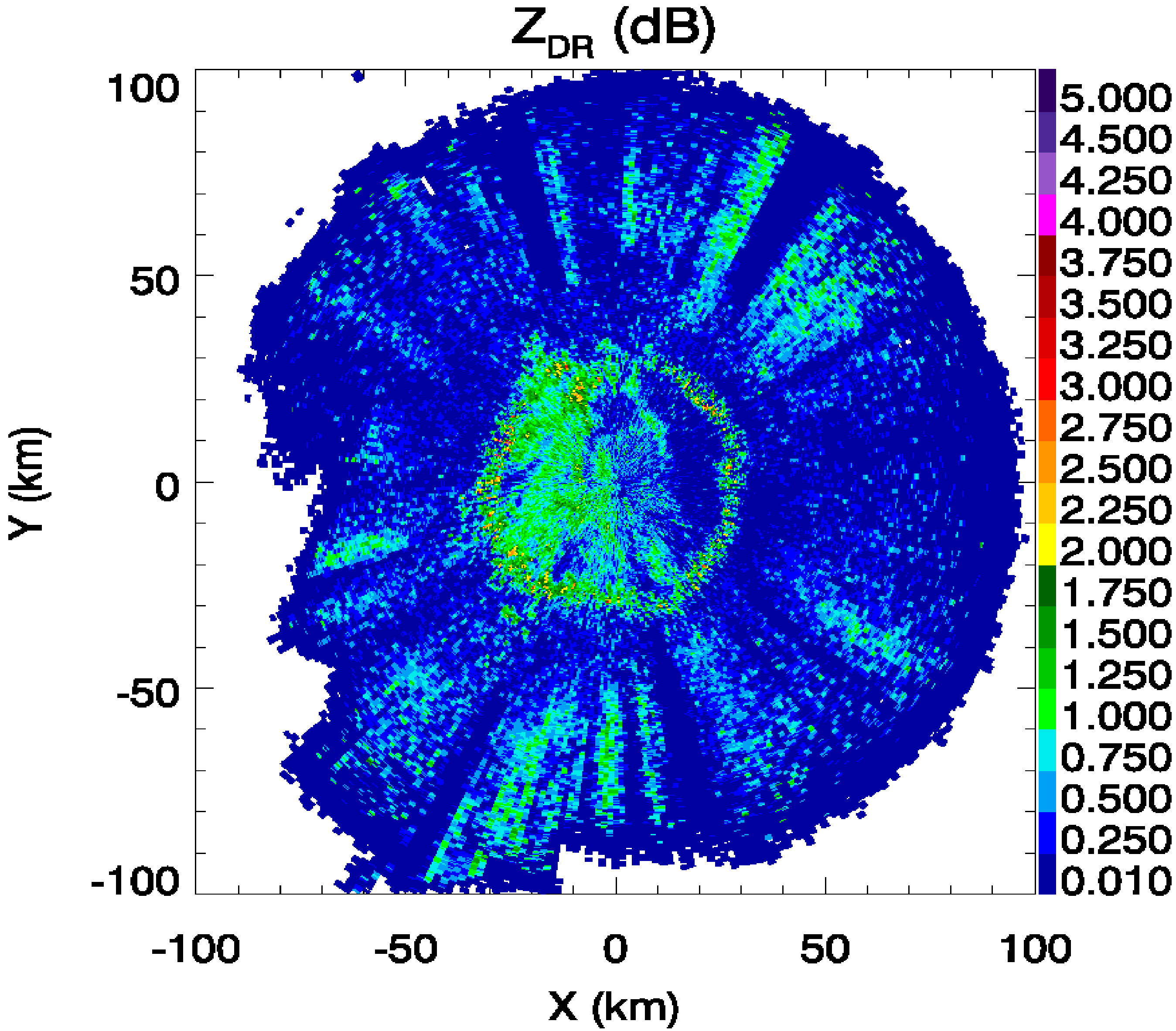


HEWLETT-PACKARD SCALAR NETWORK ANALYZER SYSTEM 8756A/S

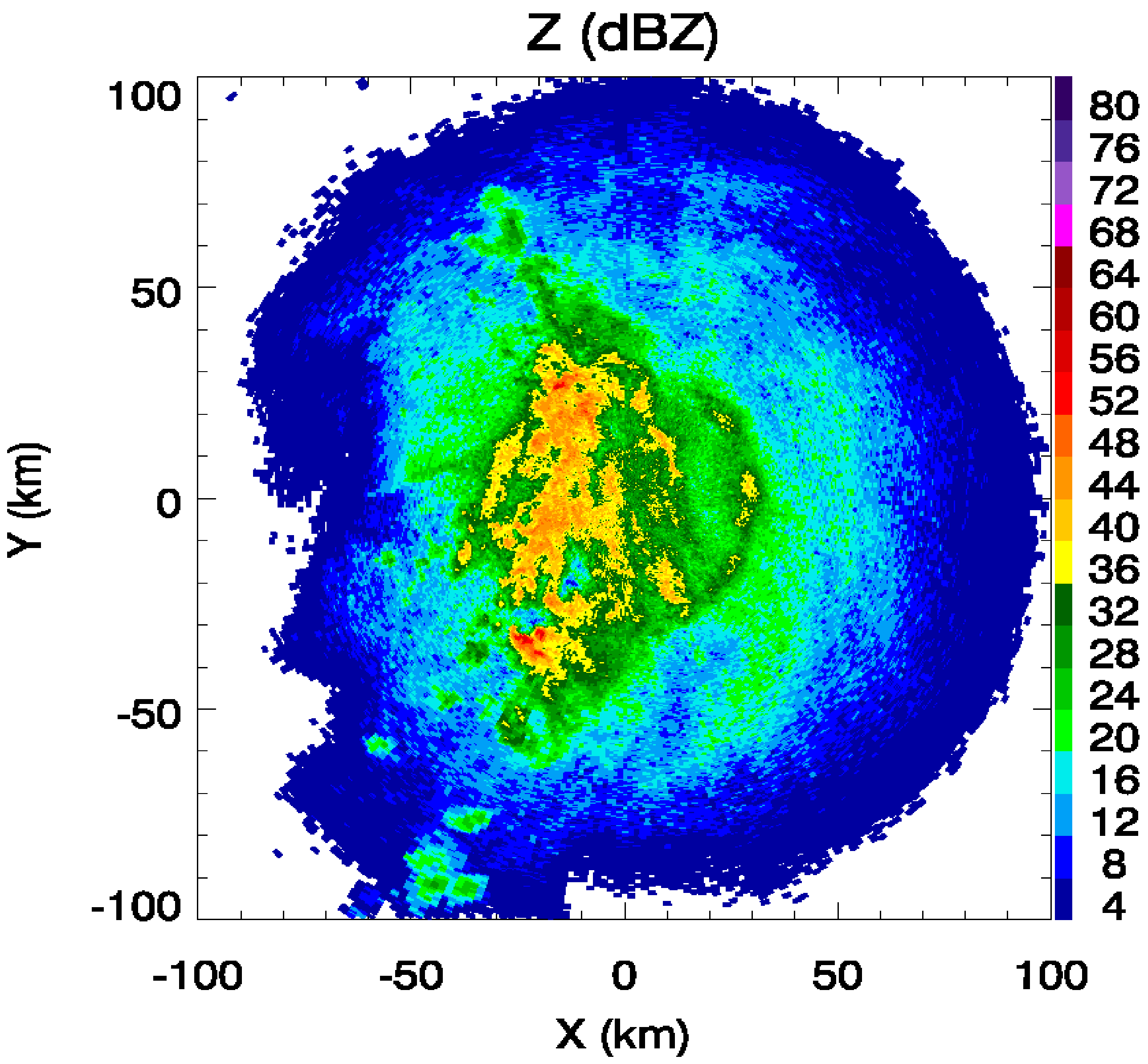
Return Loss ____ at ____ port Axial Ratio ____ Cross Polarization ____ Swept Gain ____
Isolation ✓ between ports END and SIDE Insertion Loss between ports ____ and ____

SEAVEY ENGINEERING ASSOCIATES, INC.
ANTENNA DESIGN AND DEVELOPMENT

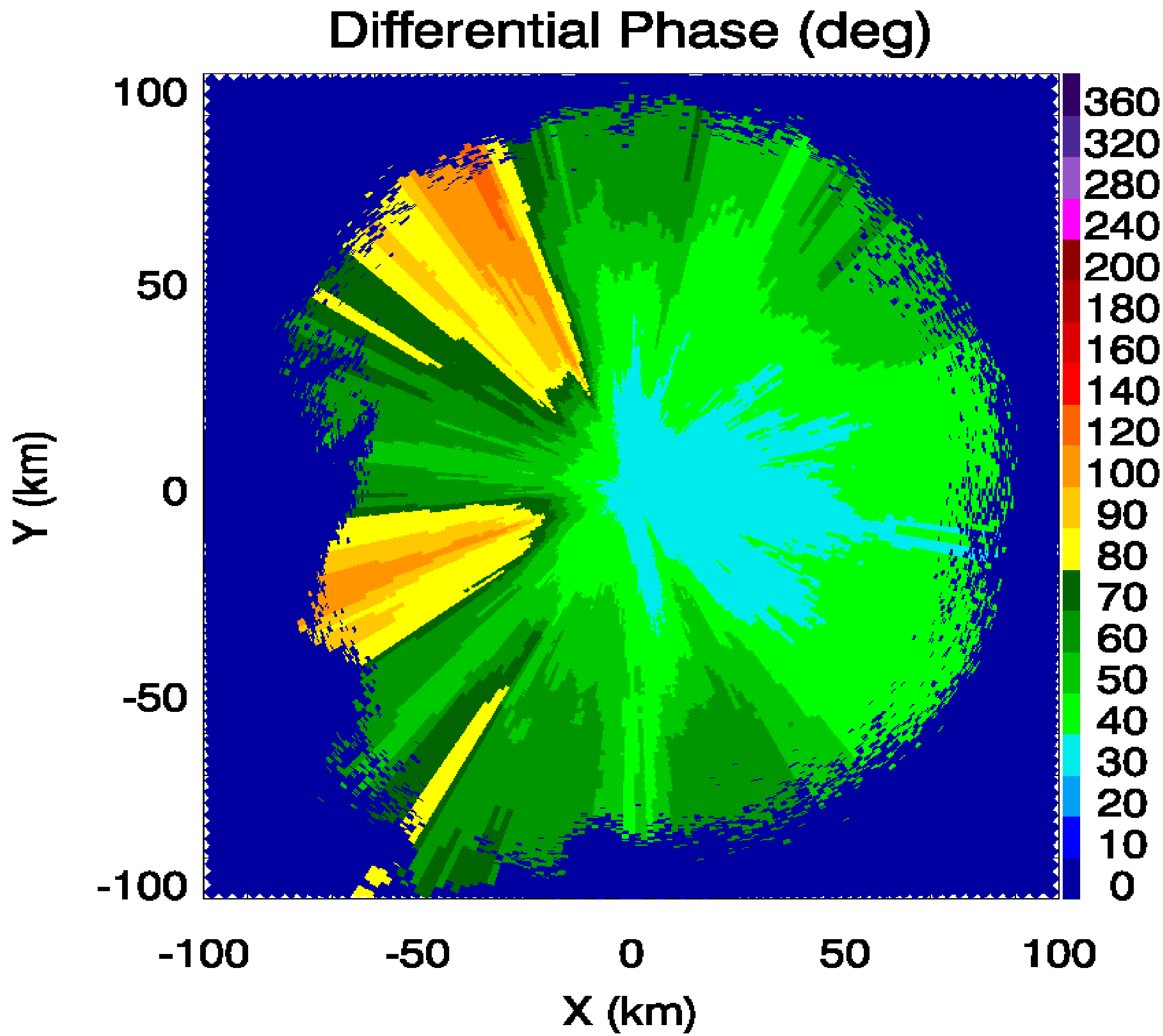
Customer Name NEXRAD
P.O. ____
Sales Order No. ____
Seavey P/N C0814-535
Model No. ____
S/N ____
Date 9/18/08
Tech. DS
Specification ____
Inspector ____
Report No. ____
Figure No. ____

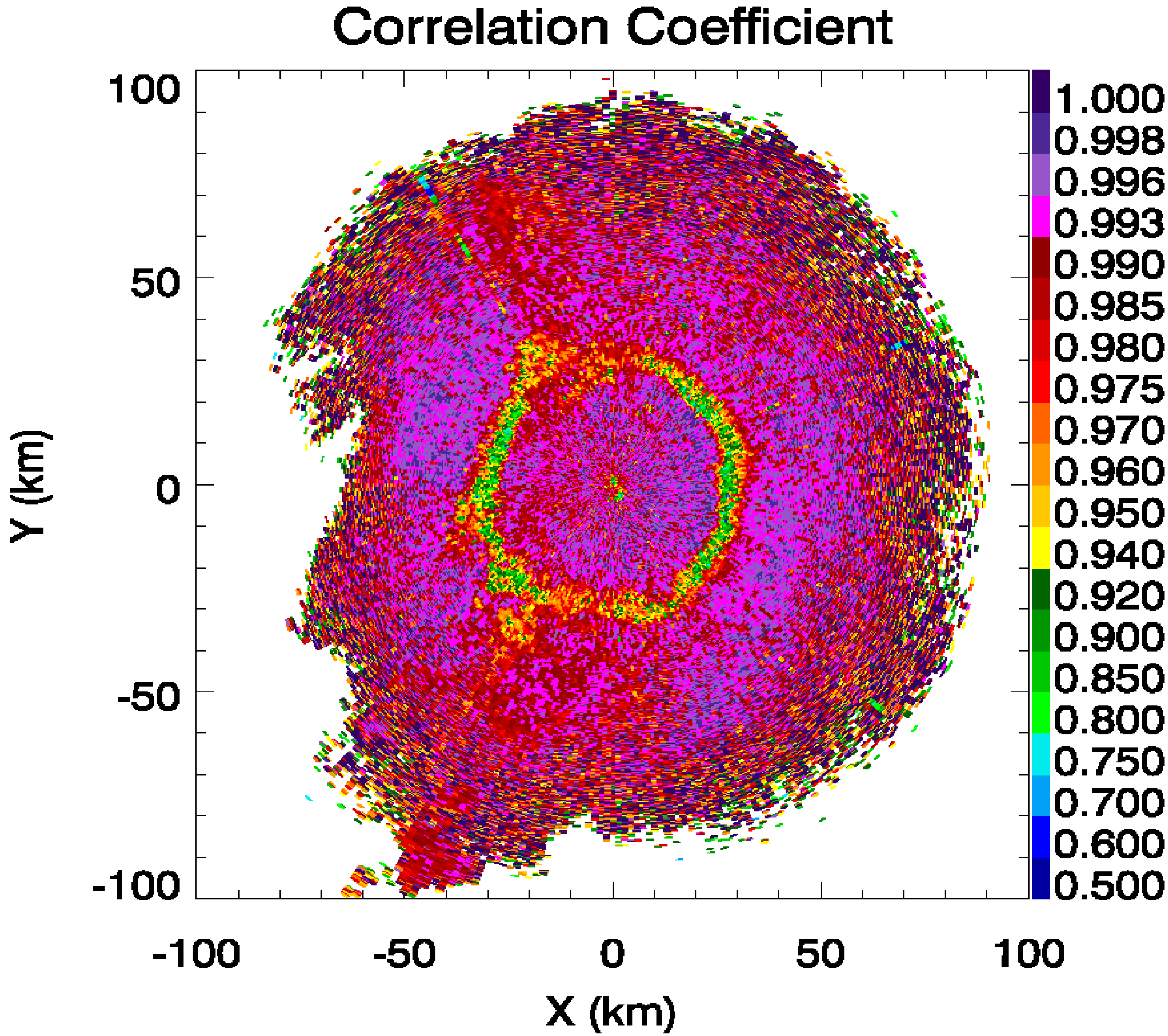


Z_{DR} (dB)
Y (km)
X (km)
100
50
0
-50
-100
-100
-50
0
50
100
5.000
4.500
4.250
4.000
3.750
3.500
3.250
3.000
2.750
2.500
2.250
2.000
1.750
1.500
1.250
1.000
0.750
0.500
0.250
0.010



Z (dBZ)
100
50
0
-50
-100
Y (km)
-100
-50
0
50
100
X (km)
80
76
72
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4


Differential Phase (deg)
Y (km)
X (km)
100
50
0
-50
-100
-100
-50
0
50
100
360
320
280
240
200
180
160
140
120
100
90
80
70
60
50
40
30
20
10
0


Correlation Coefficient
Y (km)
X (km)
100
50
0
-50
-100
-100
-50
0
50
100
1.000
0.998
0.996
0.993
0.990
0.985
0.980
0.975
0.970
0.960
0.950
0.940
0.920
0.900
0.850
0.800
0.750
0.700
0.600
0.500