Differential Reflectivity Calibration
With a Focus on the Cross Polarization Power Technique

For Determining System Bias
as
Applied to the WSR-88D

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(TAC)
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Rich Ice, ROC Engineering Branch, Air Force TAC Member
Outline for Today

• The Problem: determining “System ZDR”
• Review the delivered baseline calibration method
• Introduction to the Cross Polarization Power Method
• Project status
• The Challenges
• Sample of Recent Results
• Summary
• Continuing Efforts
**Understanding ZDR Errors**

< 0.1 dB uncertainty in the bias measurement is desired

Measured ZDR values → Radar System → Expected ZDR values

- In general, Differential Reflectivity (ZDR) is the ratio of H power to V power
  - If H=V, then ZDR is 1 (and 10*\log_{10}(1) = 0 dB, units of ZDR)
- There can be a ZDR introduced by the system
  - Referred to as System Differential Reflectivity (ZDR_{sys})
  - Here, different transmit (tx) and receive (rx) line lengths represent bias
  - The antenna also introduces a bias component
- Differential reflectivity component of the system affects all measured ZDR values
  - It imparts an undesirable bias to the estimate
  - Thus, we try to account for and remove it from the measured ZDR values
Critical System Elements that Introduce Bias
(These must be measured and monitored)

Antenna Mounted Hardware

Rx H

Receiver Bias

Tx

Power Divider

Transmit Bias

Rx V

Antenna

Calibration Reference Plane

to signal processor

Antenna bias
Current Calibration Method – Transmit Bias

Requires Measuring the “Power Sense Bias” Imparted by the built-in test equipment

Transmit Bias = H Power – V Power – Power Sense Bias
Built in Test System Functions
Current Calibration Method – Receiver Bias

Requires Measuring the “Test Signal Bias” Imparted by the built-in test equipment

Receiver Bias = Receiver Power Difference – Test Signal Bias
Measuring the Power Sense and Test Signal Bias

This is done with the “Crossed and Straight” calibration

\[ G_H * H_{ts} - G_H * V_{ts} = H_{ts} - V_{ts} \]

Example for test signal bias
Current Calibration Method – Antenna Bias

Sun’s H and V Noise Powers are Equivalent

Antenna Bias = Sun Bias – Receiver Bias
Baseline Method Summary

• Requires disconnecting and reconnecting cables, which can introduce some uncertainty

• However, analysis shows errors should cancel out if all steps are accomplished correctly
  – Power sense and test signal bias crossed and straight tests have to be done together
  – Consistency checks must yield results within expected tolerances
  – Sun check subtest 3 must be run
  – Adaptation data must be updated

• Issues with ZDR calibration continue to be observed at some sites
Example of Differential Reflectivity In Stratiform Rain
January 9, 2013

Errors in calibration are observed in some radars using current method.
Cross Polarization Power

- ROC is developing this as another check on ZDR calibration
- Cross-Polarization Power Technique (CP) is an external process
- CP has been shown to be equivalent to vertical pointing
- Actively scans ground clutter – measures cross polarization power
- Passively scans the sun
- Can provide an independent measure of the radar bias (at the time of the test)
- Pioneered at NCAR and CSU
The Cross Polar Power Technique

• Cross-Polarization Power Technique (CP) is built on the principle of radar reciprocity of cross-polarization power in dual polarization radars
  – Specifically, the two cross-polar members of the radar scattering matrix are equal; i.e., $S_{hv} = S_{vh}$
  – NCAR has shown CP to be equivalent to vertical pointing

• The technique consists of two main steps
  – Measure the combined antenna and receiver bias by scanning the sun
  – Scan ground clutter in two steps to measure transmit and receive bias
    • Transmit all H, receive V, then Transmit all V, receive H
    • Must revisit same clutter target volume for all H and all V scans
    • Antenna gains and common waveguide losses cancel

• To achieve the desired uncertainty of the bias measurement (0.1 dB), it is critical to accumulate enough data to minimize variance
  – Antenna positioning must be reliably repeatable
  – System must be reasonably stable during test data acquisition
The CP Technique

• The equation for Cross-polarization Power Technique is:

\[
Z_{dtrue} = Z_{meas} \frac{CP_{xv}}{CP_{xh}} \cdot (Sun)^2
\]

- Where
  - \(Z_{meas}\) is the measured Zdr that includes any bias introduced by the radar system
  - \(CP_{xv}\) is the clutter scan of transmit H, receive V
  - \(CP_{xh}\) is the clutter scan of transmit V, receive H
  - \(Sun\) is the measured sun bias which is equal for the co-polar and cross-polar measurements

Cross Polar Power Demonstration

**CP\(_{xh}\)**

Transmit “All H”

Receive Cross Polar V

**Ground Clutter Targets**

**CP\(_{xv}\)**

Receive Cross Polar H

Transmit “All V”
Solar Scan Demonstration

Sun’s H and V Noise Powers are Equivalent

“Sun”

\[
\frac{G^A_V \cdot W_V \cdot C^R_V}{G^A_H \cdot W_H \cdot C^R_H} = \frac{G^R_V}{G^R_H} = \frac{G_H}{G_V} = \text{Sun}_V
\]

\[
\frac{G^A_H \cdot W_H \cdot C^R_H}{G^A_V \cdot W_V \cdot C^R_V} = \frac{G^R_H}{G^R_V} = \frac{G_V}{G_H} = \text{Sun}_H
\]
Mathematical Demonstration

"Intrinsic $Z_{DR}$"

$Z_{dr} = \frac{\langle |S_{HH}|^2 \rangle}{\langle |S_{VV}|^2 \rangle}$

**Measured Zdr**

$Z_{drm} = \frac{R_H}{R_V} = \frac{P_H C_H^T W_H G_H^A}{P_V C_V^T W_V G_V^A} \frac{\langle |S_{HH}|^2 \rangle}{\langle |S_{VV}|^2 \rangle} \frac{G_H^A W_H C_H^R G_H^R}{G_V^A W_V C_V^R G_V^R}$

**Cross Polar Powers**

$\frac{CP_{xH}}{CP_{xV}} = \frac{P_H C_H^T W_H G_H^A}{P_V C_V^T W_V G_V^A} \frac{\langle |S_{VH}|^2 \rangle}{\langle |S_{HV}|^2 \rangle} \frac{G_V^A W_V C_V^R G_V^R}{G_H^A W_H C_H^R G_H^R}$

For simplicity, assume transmit powers are the same for operations and cross pol power tests (true Condition for S-Pol)
\[ Zdr_{\text{true}} = Zdr_{\text{meas}} \cdot \frac{CP_{xv}}{CP_{xh}} \cdot (Sun)^2 \]

All terms except the “true” Zdr cancel
Data Examples from WSR-88D System

Cross Polarization Power Ratio Scatter Plot
(separate H and V clutter scans)

Solar Scan Data
H power (left)
H/V power ratio (right)
Project Status

• Algorithm Delivered
  – by National Center for Atmospheric Research (NCAR)
  – NCAR providing continuous support to implementation
  – Adapting S-Pol Methods to WSR-88D

• Solar Scan Development In Progress
  – Implementing test only software in Build 14.0
  – Potentially more robust than baseline reflector bias measurement
  – Goal is to reduce calibration errors related to antenna
  – Currently investigating observed diurnal variance in reflector bias

• Clutter scans also challenging
  – Antenna positioning precision/stability problematic
    • Difficulty returning to same clutter target volume between H and V scans
    • Violates algorithm reciprocity assumption
  – Refined scan strategy to mitigate pedestal performance impacts
  – Also developing data filtering methods to compensate
    • signal to noise ratio, coherency, and linear depolarization ratio
WSR-88D Pedestal Precision and Stability affect the algorithm’s reciprocity assumption

ROC testing has included scanning, stationary, and locked pedestal data acquisition methods

Focusing on a method that establishes consistent initial conditions for each elevation scan and includes data filtering

Note: The S-pol antenna controller has an order of magnitude better precision
Challenge: Adapting Research Methods to the Operational Radars

S-pol vs. WSR-88D
Transmit Power Control

On S-pol, cross polar test mode transmit powers are the same as the powers in the operational mode.

On the WSR-88D, this is not the case.

Need to measure ratio of the cross polar test and operational mode transmit powers for both H and V.
S-pol antenna has a symmetrical structure

WSR-88D structure is not symmetrical with respect to H and V

The WSR-88D has a radome

Potential differences in reflector bias behavior?
S-pol’s reflector has a more rigid structure

Potential differences in reflector bias behavior?
WSR-88D Low Noise Amplifiers are not environmentally controlled but are temperature compensated.

Gain: +/- 0.5 dB, -40 to +54 deg C

S-pol electronic components are in a climate controlled shelter.
Reflector Bias

Measured on KOUN
S-pol sun scan data reported previously

Hubbert et al NCAR Report, ERAD, and 24th IIPS
Latest results of filter design and testing from NCAR

New Thresholds:

- $\text{Hcpa}_\text{co}$ between $0.5$ and $0.995$
- $\text{Vcpa}_\text{co}$ between $0.5$ and $0.995$
- $|\text{Hcpa}_\text{co} - \text{Vcpa}_\text{co}| < 0.4$
- $(\text{Hsnr}_\text{cross} + \text{Vsnr}_\text{cross})/2$ between $10$ and $70$
- $|\text{Zdr}_\text{copolar}| < 4$
- $(\text{Hldr} + \text{Vldr})/2$ between $-25$ and $-5$
- $(\text{Hsnr}_\text{co} + \text{Vsnr}_\text{co})/2$ between $30$ and $70$
Summary

• Pedestal accuracy and stability impact a basic algorithm assumption related to the cross polarization power clutter ratio measurements.
  – Reciprocity requires same clutter targets
  – Scan methods, large data sets, and filtering may mitigate

• There is an observed variation in the antenna reflector bias as we currently measure it.
  – Cause unknown
  – This also affects the baseline method
Continuing Efforts

• Incorporate an engineering version of Cross Polarization Power method in a near term build
  – Continue developing clutter power ratio filters
  – Integrate with baseline calibration monitoring process
  – Update algorithm

• Continue testing in Norman (KCRI and KOUN)
• Investigate reflector bias variance further
• Consider a limited field test.