Calibrating differential reflectivity on the WSR-88D

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Content

• Effects of $Z_{DR}$ bias
  – On rainfall measurements
  – On classification of hydrometeors

• Calibration Procedure
  – Version I: Accounting for all links in the transmitter and receiver paths
  – Version II: Ignoring part of the transmitter path (waveguides to outside of radome)
Effects of bias on Rainfall Measurements

RMS error of Best R(Z) = 0.35%

Bias=0.28%
Effects of Bias on Rainfall Measurements

• If the bias in $Z_{DR}$ is 0.2 dB
  – the polarimetric rainfall relation $R(Z, Z_{DR})$ used at moderate rainfall rates (6 to 50 mm h$^{-1}$) are at least as good (rms errors = 35%) as the $R(Z)$ relation
  – at most values of $Z_{DR}$ the rms errors are smaller

• If the bias in $Z_{DR}$ is 0.1 dB
  – the rms errors in the polarimetric rainfall estimates are smaller than 20%
Effects of Bias on Classification

- Width of the transition region = 0.1 dB
- Bias=0.1 dB
- Bias=-0.1 dB
- "Cold" snow (-5°C)
- "Warm" snow (~0°C)
Effects of Bias on Classification

Width of transition region, no bias

Width of transition region, bias=0.1 dB

$W_i(Z_{DR})$
Calibration Needs for the WSR-88D Network

• Calibration at time of retrofit – therefore:
  – Meteorological scatterers – OUT
  – Ground scatterers – POSSIBILITY
  – Sun – POSSIBILITY
  – Instruments - REQUIRED

• Maintain calibration all the time – therefore:
  – Automatic procedure at end of each volume scan - REQUIRED

• Least disturb the system
Calibration Points for $Z_{DR}$ measurements all paths included
Procedure

1) Separate bias in the time invariant part $\Delta_C$ and the variable part $\Delta_{34}(P_h)$ so

$$\text{Bias} = \Delta_C + \Delta_{34}$$

$$\Delta_C = \Delta_{12} + 2\Delta_{S2} + \Delta_{23}$$

2) Obtain $\Delta_{12}$ directly – monitor transmitter power and measure powers at output of EI rotary joints.

3) To measure bias of the receiver chain use only the output of the digital receiver.
Variable Bias $\Delta_{34}(P_h)$, LNA to Dig Rec – Internal Signal Generator

Internal CW generator at input to the LNAs, 3/17/2005  UT:17:31

Graph showing the relationship between $\Delta_{34}$ and power $10\log_{10}(P_h)$ (Internal RVP8 units) with different lines representing $\Delta_{34}$ (with noise), $\Delta_{34}$ (noise corrected), and $\text{SNR}_n = 0 \text{ dB}$. The graph includes an extrapolation feature.
Variable Bias $\Delta_{34}(N_g)$ obtained with the Internal Noise Generator

$\Delta_{34}(\text{with noise})$

$\Delta_{34}(\text{noise corrected})$

$\text{SNR}_h = 0 \text{ dB}$

$\text{SNR}_h = 0 \text{ dB}$
Bias from EL joints to Dig Rec
External Generator above EL Joints

External HP Generator above the El Rotary Joints, 3/10/2005  UT:16:41

- $\Delta_{24}$ (with noise)
- $\Delta_{24}$ (noise corrected)
- $\text{SNR}_n = 0 \, \text{dB}$

Power, $10\log_{10}(P_h)$ (Internal RVP8 units)
Sun scan: $P_h$ and $P_v$, and bias component $\Delta S_4$
Constant Receiver Bias (Sun to LNA) over a five month period

Mean = -0.3 dB
SD = 0.028 dB
Bias between LNA and Dig Rec (variations over two 600 min periods)
Error Budget – Estimate

- TR to above El joints,
  - biased: \( \text{rms}(\Delta_{12}) < 0.04 \text{ dB} \)?

- EL joints to out of radome,
  - biased: \( \text{rms}(\Delta_{2S}) < 0.03 \text{ dB} \)?

- Sun to LNA
  - Difficult not biased: \( \text{rms}(\Delta_{S3}) < 0.03 \text{ dB} \)

- LNA to Dig Receiver,
  - Difficult not biased: \( \text{rms}(\Delta_{34}) < 0.04 \text{ dB} \)

Total SD value < 0.1 dB
Calibration of ZDR on the WSR-88D
Version I: PROCEDURE

• The procedure uses existing components on the WSR-88D and the Sun
• The bias consists of a constant part and a time varying part
• The constant bias is obtained from three sets of measurements (one in the transmission chain two in the receiver)
• The time varying part must be measured automatically at the end of each volume scan
• Measurement over any part of the active receiver path must be preceded and followed by automated rapid measurement of the active part
Calibration of $Z_{DR}$ on the WSR-88D

Version I: FINDINGS

- The $Z_{DR}$ BIAS is constant over the dynamic range of the receiver
- Coherent leakage caused by the internal frequency generator
  - SOLUTIONS:
    - EXTRAPOLATE THE VALUES FROM HIGH POWERS TO LOW POWERS
    - VERIFY WITH INTERNAL NOISE GENERATOR
- Abrupt discontinuities in bias caused by differential temperature in the LNA enclosures
  - SOLUTIONS:
    - AUTOMATIC CALIBRATION AT END OF VCP
    - FORCE TEMPERATURE CONTROL IN THE TWO ENCLOSURES TO BE THE SAME
- The SUN is an excellent source for calibration
  - IT HAS ZERO BIAS
  - SD OF ERROR CAN BE MADE MUCH SMALLER THAN 0.1 dB
- Achievable rms error should be ~ 0.1 dB
VERSION II: Calibration of $Z_{DR}$ excluding path 2 (EL joints) to SUN

Input – absolute
No Bias $P_h = P_v$

Two channels H and V

Digital Receivers

Output – absolute
Bias and Variance

Transmitter

Power Splitter

TR circuits

El Rot joints

Input – internal Gen
Bias inconsequential

Calibration Ports

Output

S

1

2

3

4
Variable Bias $\Delta_{34}(P_h)$, LNA to Dig Rec – Adjustment using Sun scan

Internal CW generator at input to the LNAs, 3/17/2005  UT:17:31

Power, $10\log_{10}(P_h)$, (Internal RVP8 units)
Repeated Measurements – Transmission Path above EI Joints

• Two power meters, 15 measurements:
  – Mean = -0.057 dB, SD = 0.006 dB

• One power meter, connected and disconnected 10 times
  – Mean = -0.088 dB, SD = 0.004 dB

• Previous measurement: Mean ~ -0.06 dB
Error Budget – Estimate

• TR to above EL joints,
  - biased: \( \text{rms}(\Delta_{12}) < 0.03 \text{ dB?} \)

• EL joints to out of radome,
  - ignore: \( \text{rms}(\Delta_{2s}) < 0.06 \text{ dB?} \)

• Sun to Dig Receiver
  - Easy not biased: \( \text{rms}(\Delta_{3s}) < 0.03 \text{ dB} \)

Total rms value < 0.08 dB
Calibration of ZDR on the WSR-88D Version II: PROCEDURE

• The procedure uses existing components on the WSR-88D and the Sun
• The bias consists of a constant part and a time varying part
• The constant bias is obtained from two sets of measurements - one set has no BIAS
• The time varying part must be measured automatically at the end of each volume scan
• Much easier to make in the field
Calibration of ZDR on the WSR-88D Version II: FINDINGS AND ISSUES

• Sun - equality of the H and V polarizations
  – NCAR’s redundant measurements during quiet (no sun spots) period indicate excellent match

• Sun – standard deviation of measurements
  – NSSL’s result ~ 0.028 dB
  – NCAR’s result ~ 0.024 dB

• Measurement in the transmitter chain
  – Bias at couplers above EL rotary joints
  – Value of ignored bias from the EL joints to outside of radome
Measurement in Drizzle: Z Field

KOUN, Norman, OK. SHV mode
02/06/2005 02:28 UT RHI Az=240.9 deg

Z (dBZ)
Measurement in Drizzle: $Z_{DR}$ Field
Histogram of $Z_{DR}$ in Drizzle

Adjustment using only Sun's $Z_{DR}$

$\langle Z_{DR} \rangle = 0.01$ dB
Path to Resolution

• NSSL measurement on the RRDA
  – Automatic part of calibration has been implemented, it enables perfect relative tracking of the bias
  – Compare results from the procedure with measurements in precipitation at 60 deg elevation

• NWS to check the precision and bias of the couplers?

• NCAR measurements?
END
Total number=7698
SNR >20 dB
$<Z_{DR}> = -0.55$ dB
Total number = 7698
SNR > 20 dB
$<Z_{DR}> = -0.55$ dB
Procedure - continuation

4) Precede and follow the measurement at the output of the digital receiver with the measurement from the calibration port
   – For example obtain $\Delta_{23}$ as $\Delta_{23} = \Delta_{24} - \Delta_{34}$, by measuring first $\Delta_{34}$ then $\Delta_{24}$ and again $\Delta'_{34}$
   – Accept the measurement if $\Delta_{34}$ and $\Delta'_{34}$ are within 0.03 dB!

5) Sun scan followed immediately by noise power measurements in each channel $N_h$ and $N_v$ - subtract these from the total powers $P_h$ and $P_v$

6) Internal noise generator and sun scan to measure $\Delta_{S4} - \Delta_{34}$

7) Internal signal generator and external generator to obtain $\Delta_{24} - \Delta_{34}$

8) Compute

$$\Delta_{S2} = \Delta_{S4} - \Delta_{34} - (\Delta_{24} - \Delta_{34})$$