Operational considerations for Zdr Calibration using the Cross-polarimetric Technique

GREGORY MEYMARIS*
National Center for Atmospheric Research, Boulder, Colorado

JOHN HUBBERT
National Center for Atmospheric Research, Boulder, Colorado

MIKE DIXON
National Center for Atmospheric Research, Boulder, Colorado

RICH ICE
Radar Operations Center, Norman, OK

ADAM HECK
Radar Operations Center, Norman, OK

1. Introduction

For quantitative precipitation estimates it is desirable to calibrate Z_{dr} to 0.1 dB. However, determination of the Z_{dr} calibration figure and maintenance of that calibration is difficult. Hubbert (2008); Hubbert et al. (2007) compared three Z_{dr} calibration techniques: 1) vertical pointing (VP), 2) crosspolar power (CP), and 3) engineering techniques. Probably the mostly widely accepted technique is VP, using vertical pointing data in light rain. It works well since it is an "end-to-end" method that exercises the full transmit and receiver paths as they would be for meteorological measurements. Engineering techniques attempt to estimate the Z_{dr} calibration factor by injecting test signals and using passive measurements of solar radiation. However, the uncertainties introduced by the calibration test equipment, the uncertainty of the engineering Z_{dr} calibration technique is 0.25 dB at best, at least for the engineering techniques investigated by Hubbert (2008). The third method, the CP technique, uses solar scan data and crosspolar power data to calibrate Z_{dr} Hubbert, J.C. and V.N. Bringi (2003). This technique is similar to the VP technique in that no obtrusive calibration test equipment is used. The crosspolar power (CP) technique uses the principle of radar reciprocity that states that the two crosspolar powers are equal under the assumption that the H and V transmit powers are equal. It has been shown that the CP technique can calibrate Z_{dr} to a similar uncertainty (< 0.1dB) as is possible with the VP technique (Hubbert 2008). At some sites, the weather conditions necessary for the VP technique may be rare, making the CP technique attractive.

Both S-Pol and CSU-CHILL typically run dual polarization in fast alternating mode (i.e. alternating pulses of H and V power). Backscatter targets typically do not change much in such short time intervals so that the correlation between the crosspolar powers is high. Thus, S-Pol and CSU-CHILL can use both precipitation targets as well as ground clutter targets for CP calibrations.

The NEXRAD radars, on the other hand, transmit H and V simultaneously. Additionally, it is not possible to switch from transmit H to transmit V modes quickly, requiring around a minute. Thus the CP method requires adaptation to work on this platform. In particular, a natural step is to transmit H and V on alternating PPI scans. Because of the longer times between the data collection of H and V transmit (minutes), it becomes necessary to only look at

**Corresponding author address*:
Gregory Meymaris, RAL, NCAR
1850 Table Mesa Dr., Boulder, CO 80305
meymaris at ucar dot edu

stationary ground clutter targets.

Currently, the CP technique is being investigated and tested for use on the NEXRADs. This paper examines the practical, operational considerations for using the CP technique, focusing on the cross-polar power ratio estimation, a key component of the technique. Data from KCRI (the Radar Operation Center's S-band testbed radar) are used.

2. The Crosspolar power technique for NEXRAD

The CP method is described elsewhere (Hubbert, J.C. and V.N. Bringi 2003). The technique uses the property of radar reciprocity (Saxon, D.S. 1955) which states that the off diagonal terms of the radar scattering matrix, S_{hv}, S_{vh}, are equal (Bringi and Chandrasekar 2001). Using this fact the Z_{dr} calibration equation can be derived:

$$Z_{dr}^{cal} = Z_{dr}^{m} S^2 \overline{\left(\frac{P_{RHX}}{P_{RVX}}\right)} \qquad (1)$$

where Z_{dr}^{cal} is calibrated Z_{dr}, Z_{dr}^{m} is measured Z_{dr}, S is the ratio of the V and H powers from sun measurements, and $\overline{(P_{RHX}/P_{RVX})}$ is the average crosspolar power ratio for transmit V and transmit H polarization pairs. The crosspolar power ratios may be averaged over a few rays or an entire volume of radar data. Both precipitation as well as *ground* clutter targets may be used. The CP Z_{dr} calibration approach is like the VP technique in that neither require waveguide couplers, signal sources nor power meters and thus the associated uncertainty related to such RF measurements is eliminated.

Both CSU-CHILL and S-Pol employ a copolar and crosspolar receiver design in contrast to H and V receivers. To accomplish this, CSU-CHILL uses a switch after the low noise LNAs of the receivers whereas S-Pol uses a switch at the IF (intermediate frequency) stage. Having copolar and crosspolar receivers reduces the variance and drift of the Z_{dr} measurement but this also slightly changes the Z_{dr} calibration equation to:

$$Z_{dr}^{cal} = Z_{dr}^{m} S_1 S_2 \overline{\left(\frac{P_{RHX}}{P_{RVX}}\right)} \qquad (2)$$

where S_1 is the ratio of V-copolar to H-copolar sun radiation and S_2 is the ratio of V crosspolar to H crosspolar sun radiation (See Hubbert, J.C. and V.N. Bringi (2003) for details).

For NEXRAD, the situation becomes more complicated because the radar can not transmit in fast alternating mode, among other reasons. Figure 1 shows a block diagram of the NEXRAD simultaneous H and V (SHV) dual polarized system. The system is similar to S-Pol; however, instead of employing a Magic-T and wave guide switches to allow for SHV, H and V only transmit modes, NEXRAD uses two 90 degree hybrid couplers with a ferrite phase shifter. Consequently, the H and and V only paths are electrically distinct from the H and V paths in SHV mode. If the beams are indexed, crosspolar powers from the same resolution volumes (but from different PPI scans) can be paired and used for the CP calibration. However, terms that would normally cancel out, no longer do. This is because the assumption that the receiver gains and the transmitter powers do not change from measurement of the P_{RHX} to P_{RVX} is no longer a good one. The calibration equation becomes:

$$Z_{dr} = Z_{dr}^{m} T_m G_{Rm} S^2 \overline{\left(\frac{P_{RHX}}{P_{RVX}}\right)} T_c^{-1} G_{Rc}^{-1} \qquad (3)$$

where T_m is the ration of the V to H transmitter powers during operations, G_{Rm} is the ratio of the V to H receiver gains during operations, T_c is the ratio of the V to H transmitter powers during the calibration period (when the radar will transmit H only and then V only PPIs), and G_{Rc} is the ratio of the V to H receiver gains during the calibration period.

The principle of reciprocity states that the two crosspolar power measurement (transmit H receive V (P_{RVX}) and transmit V receive H (P_{RHX}) are equal. Since NEXRAD uses SHV mode, the P_{RHX} is measured for one low level PPI scan (in clutter) and then P_{RVX} is measured in the next PPI. The two crosspolar power can then be compared and used to estimate the average ratio $\overline{P_{RHX}/P_{RVX}}$ as required by the CP technique. This turns out to be difficult for various reasons. First, according to the the transmit burst powers as measured by the Open Radar Data Acquisition (ORDA) system (SIGMET RVP8), which is measured after the transmitter (see the "DAU" box near the top left of figure 1), the transmitter power fluctuates. See figure 2 for an example of the measured burst pulses on KCRI. This plot shows a time-series plot of the burst-pulse power as measured by the SIGMET RVP8 while the radar was running a test calibration sequence of H- (red) then V- (blue) only transmit PPIs. Just before the first H-only PPI, the radar performed a sun measurement. Mixed in between some PPIs, there are transmit power measurements (for T_c) and receiver bias measurements (for G_{Rc}) taken. There are several important points to note about this plot. First, there are large discontinuities in between PPIs, though

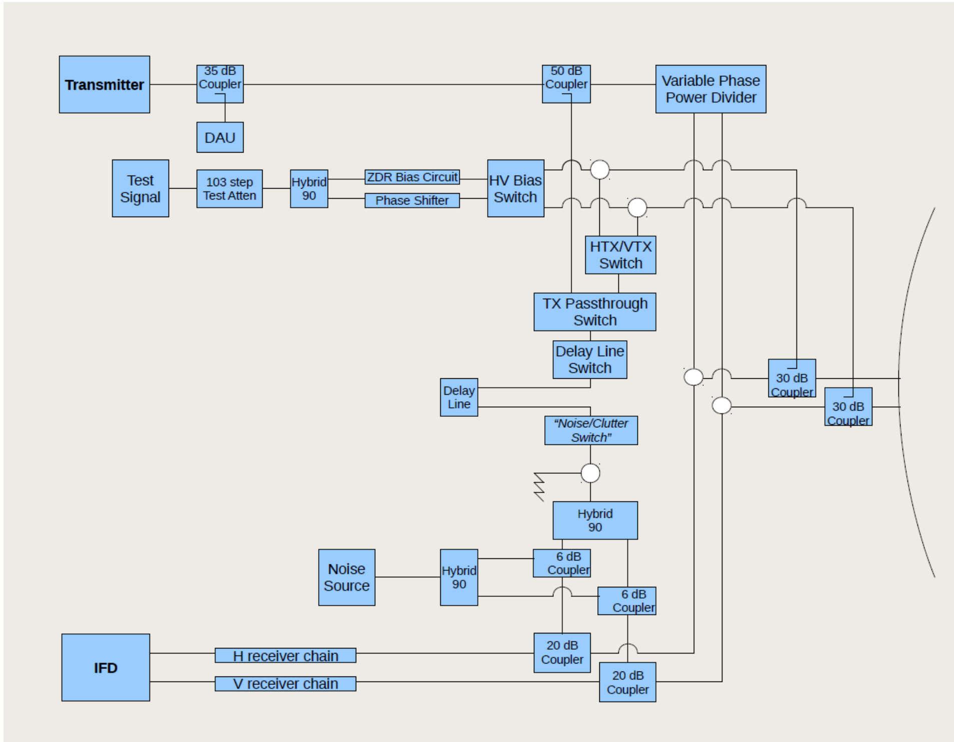

Figure 1: block diagram of the NEXRAD simultaneous H and V dual polarized system. Source: NEXRAD Radar Operations Center (ROC)

this biggest occurs near the beginning of the sequence. Second, within a single PPI there is a general downward trend in power, as much as 0.5 dB (ignoring the first PPI for the moment). Third, there is an overall downward trend of maybe 2.5 dB. Fourth, there appear to be some large fluctuations, around ± 0.05 dB, in the first two PPIs. Assuming that the burst pulse power measurements are reliable, and there is little reason to question it at this point, it becomes clear that the transmitter fluctuations are too large to ignore, recalling that a bias of less than 0.1 dB is desired.

One cannot simply use the burst pulse measurement as a substitute for the H/V transmit power measurements because of its placement in the topology, especially because it is upstream from the phase shifter. However, if we can assume that the drifts between the burst pulse power and the H and V power sense measurements (taken right upstream from the antenna in figure 1 as part of the estimate of T_c) varies slowly over time, then we can use the burst pulse power to continuously adjust $\overline{P_{RHX}/P_{RVX}}$. The Z_{dr} calibration equation becomes

$$Z_{dr} = Z_{dr}^m T_m G_{Rm} S^2 \overline{\left(\frac{P_{RHX}}{P_{RVX}} \frac{P_{BRV}}{P_{BRH}}\right)} \frac{O_H}{O_V} G_{Rc}^{-1} \quad (4)$$

where P_{BRH} is the burst pulse power during the same time that P_{RHX} was estimated (likewise for P_{BRV}) and O_H, and O_V are the offsets between the burst pulse power and the H and V (resp.) power sense measurements, estimated at the time of the power sense measurements.

3. Experimental data

I and Q data from H and V transmit only $0.5°$ elevation PPI scans were recorded from KCRI (the NEXRAD Radar Operations Center's test-bed radar) during a period from 2013-04-29 to 2013-05-01. There are many different steps to the calibration test that was run, but the relevant part for this paper is that after an H-transmit only scan, the radar was parked, switched to V-transmit only, and a V-transmit PPI scan was performed. After some power sense measurements, the process repeated, switching H and V.

An additional operational consideration for computing $\overline{P_{RHX}P_{BRV}/P_{RVX}P_{BRH}}$ is that there needs to be a criterion for limiting the gates used to stationary ground clutter targets with reasonable signal-to-

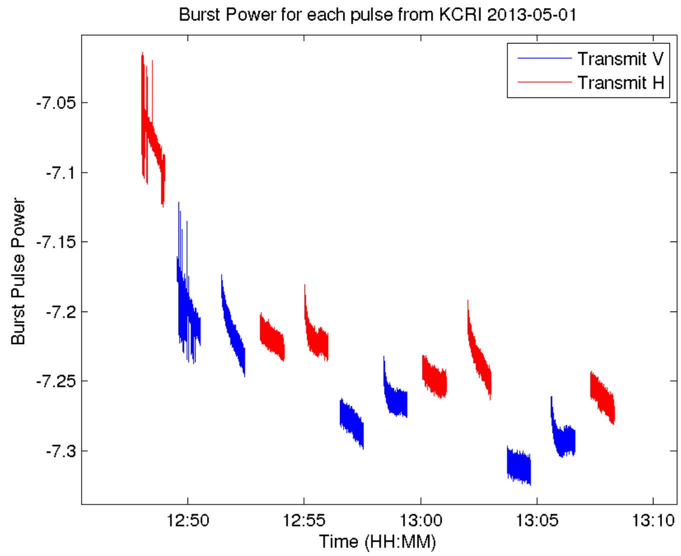

Figure 2: Measured pulse-by-pulse burst power from ORDA on KCRI, taken on 2013-05-01 around 13Z. The blue lines are data taken during transmit V only scans, while the red are during transmit H only scans.

noise ratios. The criteria used for this analysis were:

$$\begin{aligned} C_{HC} &> 0.5 \\ C_{VC} &> 0.5 \\ \frac{SNR_{HX}+SNR_{VX}}{2} &\geq 10 \\ \frac{SNR_{HX}+SNR_{VX}}{2} &\leq 70 \\ |Z_{dr}^{m}| &< 5 \\ \frac{LDR_{H}+LDR_{V}}{2} &\geq -20 \\ \frac{LDR_{H}+LDR_{V}}{2} &\leq 0 \\ \frac{SNR_{HC}+SNR_{VC}}{2} &\geq 45 \\ \frac{SNR_{HC}+SNR_{VC}}{2} &\leq 70 \end{aligned}$$

where C_{HC}, C_{VC} are the clutter phase alignment (CPA) for the H/V transmit only copolar signal data, SNR_{HX} and SNR_{VX} are the signal-to-noise ratios for the H/V transmit only crosspolar signal data, SNR_{HC} and SNR_{VC} are the same but for the copolar signal data, and LDR_H and LDR_V are the linear depolarization ratio for H/V transmit only data (i.e. $LDR_H = SNR_{HC} - SNR_{HX}$). These thresholds were determined empirically by looking at the dependence of $\overline{P_{RHX}/P_{RVX}}$ to each of the above fields. These criteria should be revisited by looking at the dependence of $\overline{P_{RHX}P_{BRV}/P_{RVX}P_{BRH}}$ to each of the above thresholds. The CPA values help to limit the data down to ground clutter. The others are generally just sanity checks to avoid contaminants like noise and receiver saturation. Two additional criteria for each gate are: the average elevation angle for H and V must be exactly the same, and the range (maximum minus minimum) of the pulse burst power, in dB, for both H and V must be less than 0.02 dB. The former helps ensure that the radar is illuminating the target similarly, and the latter removes gates where the burst pulse is fluctuating more than usual.

The burst pulse power adjusted cross polar power ratio, namely $P_{RHX}P_{BRV}/P_{RVX}P_{BRH}$ for each gate was computed for each adjacent H and V transmit only PPI scans. The average, in dB, is then taken over all gates that satisfy the criteria. The results of this procedure for PPI scans taken from about 12Z to 17Z on 2013-05-01, are shown in the top panel of figure 3. The cross power ratio, in dB, with (black) and without (blue) the burst pulse correction are shown along with the former after an additional 11 point average filter. The lower panel shows the burst pulse power from the same H and V transmit PPI scans for reference. As can be see, the burst pulse power corrected data has reduced variance and shows almost no trending over the coarse of the time period. The standard deviation of the corrected but unsmoothed data is 0.081 dB (whereas the uncorrected data has a standard deviation of 0.095 dB). It takes approximately 10 H/V only PPI pairs in order to reduce the 95% confidence interval to under± 0.05 dB. This allows some buffer for errors

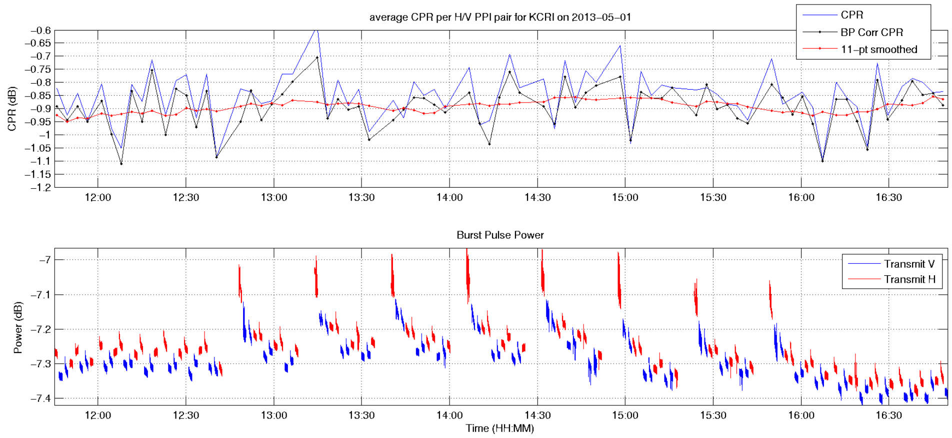

Figure 3: The top panel shows the average cross polar ratio, taken over an H/V PPI scan pair, both with (black) and without (blue) the burst pulse correction. Also shown is the former with an 11-point average filter applied. The lower panel shows the measured pulse-by-pulse burst power. Data was collected on KCRI on 2013-05-01 from about 12Z to 17Z.

from other measurements, such as the sun scans and power sense measurements.

4. CONCLUSIONS

The crosspolar power (CP) technique for calibrating Z_{dr} has been demonstrated previously to compare well with calibrations from vertical pointing data in light rain. Currently the CP technique is being investigated for possible use on the NEXRADs. The cross power ratio has been shown to need correction because of fluctuations in the transmitter power, as measured by the burst pulse. Using the burst pulse power, a correction factor can be applied that is shown to reduce the standard deviation. Longer time periods need to be examined and the assumption of the stability of the offsets between the burst pulse power and the H/V power sense measurements needs to be verified.

5. Acknowledgment

This research was supported in part by the ROC (Radar Operations Center) of Norman OK. Both the CSU-CHILL and NCAR S-Pol radars are supported by the National Science Foundation. Any opinions, findings and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the National Science Foundation or the ROC.

References

Bringi, V. and V. Chandrasekar, 2001: *Polarimetric Doppler Weather Radar*. Cambridge Univ. Press, Cambridge, UK.

Hubbert, J.: 2008, Nexrad differential rflectivity calibration. AMS 24th International Conference on Interactive Information and Processing Systems, New Orleans, LA.

Hubbert, J., F. Pratte, M. Dixon, and R. Rilling: 2007, The uncertainty of z_{dr} calibration techniques. *Preprints, 33rd AMS Conf. on Radar Meteorology*, Cairns, Australia.

Hubbert, J.C. and V.N. Bringi , 2003: Studies of the polarimetric covariance matrix: Part II: Modeling and polarization errors. *J. Atmos. Oceanic Technol.*.

Saxon, D.S., 1955: Tensor scattering matrix for the electromagnetic field. *Phys. Rev.*, **100**, 1771–1775.