Sensitivity Analysis
comparing the
WSR-88D Baseline and L3 Baron Dual Polarization Modification

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Executive Summary

This paper documents an engineering analysis of the typical sensitivity loss expected at a WSR-88D network radar site resulting from the Polarization Technology Upgrade (Dual Polarization Modification). The analysis addresses items relevant to radar sensitivity including: (1) transmitter power available at the antenna due to power division and associated hardware insertion losses, (2) antenna gain, (3) receive path losses, (4) receive path gain, and (5) receiver noise. The paper reviews the expected sensitivity changes between the Dual Polarization prototype (KOUN) and the baseline WSR-88D radar system (KCRI) used by the Radar Operations Center (ROC). Data produced by these radars is used for determining the actual performance of the prototype. However, the two radars operate at opposite ends of the allotted frequency band and as such have inherent sensitivity differences due to wavelength effects.

The ROC engineering and science teams compared the observed sensitivities between the two systems while they scan common radar resolution volumes. The team then adjusted the observed sensitivity difference between the radars by subtracting the inherent sensitivity difference expected from wavelength effects. The team also determined the expected sensitivity difference between a typical baseline WSR-88D and the dual polarization modification by comparing hardware design characteristics and factory test data.

The expected difference in sensitivity between a baseline WSR-88D and a modified system is less than 4 dB, based on hardware analysis. The observed differences obtained for three winter precipitation cases, is approximately 3.5 dB. The ROC dual polarization engineering team concludes that the sensitivity difference between a baseline and a modified WSR-88D radar will be less than 4 dB and will typically be on the order of 3.5 dB.

Methodology

The general method used in this study is summarized below.

- Use the weather radar equation, antenna theory, and observed performance to isolate the performance difference between the two test radars due to their wavelength difference
- Observe sensitivity difference in real data cases and adjust for inherent loss due to wavelength.
- Analyze hardware design, test data, and typical parameters to obtain expected sensitivity differences

  - Transmit and receive path losses
  - Receiver gain
  - Receiver noise
  - Antenna Gain
- Compare expected to observed

There is a challenge presented in using these two radars because they operate at opposite ends of the available frequency band, and thus exhibit an inherent sensitivity difference due to antenna gain, beam width, and wavelength differences. KCRI is a redundant system with two channels. Channel 2 operates at a frequency of 2995 MHz while 2950 MHz is the frequency for channel 1. These values result in wavelengths of 10.02 and 10.17 centimeters (cm) for the respective channels. KOUN operates at a frequency of 2705 MHz for a wavelength of 11.09 cm. In order to use radars at such separated wavelengths, the engineering team determined the inherent sensitivity difference between the radars from theoretical considerations and observed data using available performance parameters. Then the team observed the actual sensitivity difference from data collections in multiple weather events. The team used two major methods for estimating the sensitivity difference and these are discussed in detail. Finally the team adjusted the observed sensitivity using the expected sensitivity difference due to wavelength considerations to obtain a best estimate of the actual sensitivity difference due to the hardware modification.

Once an accurate estimate of the sensitivity difference was obtained, the engineering team then compared the observed difference with the difference expected from analyzing hardware specifications and available test data.

The team concluded that the expected sensitivity difference between KCRI and KOUN was on the order of 1.5 dB. Observations from three weather events in February and March of 2010 indicated that the raw sensitivity difference between the radars was just under 5.0 dB, and was perhaps as low as 4.7 dB. Allowing for the 1.5 dB inherent difference in the performance of the two systems the dual polarization modification effect was determined to be between 3.2 and 3.5 dB, with the dual polarization prototype being the less sensitive radar. Hardware analysis by the engineering team determined the expected sensitivity difference between the baseline and dual polarization modified radars to be less than 3.7 dB. The observed data agrees well with the results of the hardware analysis. Allowing for variations in production hardware, and uncertainty in some of the measurements, the team determined that the expected difference in sensitivity should not exceed 4.0 dB and should typically be near 3.5 dB.

The data on antenna performance for this paper, both baseline and modified, is from the elevated, open air, far field range testing conducted by ARA Seavey on January 27 and March 26 of 2009 [5]. The data for the baseline configuration is contrasted with historical data from the Andrew range testing and from current field measurements done via solar scans [2] [3].

The L3 baron team provided data on insertion losses of the relevant dual polarization modification hardware on March 11, 2010 [6]. Hardware analysis was performed for functional areas where the losses were expected to differ due to the design of the dual polarization modification.

Expected Sensitivity Differences for the Two Test Radars

This section provides and analysis of the inherent difference in sensitivity between two similar radars operating at different wavelengths. In general, for the same antenna hardware, gain will decrease with longer wavelengths and beam width will increase. For weather targets, there is an additional difference in the backscatter reflectivity due to wavelength. The following analysis is based on a simplified version of the weather radar equation (4.34) given in Doviak and Zrnic, Section 4.4.5 [1].

From equation 4.34, the power received from a radar signal illumination a volume distributed target at a specific range is:

$$P(\mathbf{r}_0) = \frac{\pi^3 P_t g^2 g_S^2 \theta_1^2 c \tau |K_W|^2 Z_e}{2^{10} (\ln 2) \lambda^2 r_0^2 l^2 l_r}$$

Where:

$P(\mathbf{r}_0)$ is the receiver output power for a resolution volume centered at $\mathbf{r}_0$
P_t is peak transmit power at the antenna port
g is antenna gain, referenced to the same port as the peak transmit power
g_s is "system gain" the total gain of the receiving system (TR, filters, amplifiers, mixers)
l is atmospheric attenuation
l_r is receiver loss, not included in g_s
θ_1 is antenna 3 dB beam width, assumes azimuth and elevation beam width match
λ is wavelength
τ is pulse width

By combining constants and parameters common to both radars into a single "radar constant" C_1, the equation reduces to:

$$P(\mathbf{r}_0) = \frac{P_t g^2 \theta_1^2 Z_e}{\lambda^2 r_0^2 l^2} C_1$$

This equation assumes that additional transmit losses not contained within the peak power measurement, and additional receiver losses, are equal for both radars. Recall that

the purpose of this analysis is merely to determine the differences due to wavelength alone. For the receiver this also assumes that the "system gain (g_s)" is the same for each radar. Other terms that are common in a simple side-by-side sensitivity analysis should be the target effective backscatter reflectivity and the range to the associated resolution volume. This means Z_e, l, and r_0 are common and can be included in a second constant, C_2.

The equation now reduces to a form containing only terms that will differ between the two radars:

$$P(\mathbf{r}_0) = \frac{P_t g^2 \theta_1^2}{\lambda^2} C_1 C_2$$

We now see that the relative capability of the two radars to generate a received power signal are dependent only on the available transmitter power at the antenna port, the antenna gain referenced to that port, the antenna 3 dB beam width, and the wavelength. Discussion on the transmit power available at the antenna port is deferred to the section on hardware analysis. Recall this section is focused on changes due to wavelength differences only.

Of particular interest is the signal to noise ratio (SNR) because this is the parameter upon which the radar output estimates are subjected to a data quality threshold. In general, the goal is to implement a system yielding the highest possible SNR for a given meteorological target resolution volume. The SNR is the ratio of the signal power to the noise power:

$$SNR = \frac{P(\mathbf{r}_0)}{P_N} = \frac{1}{P_N} \frac{P_t g^2 \theta_1^2}{\lambda^2} C_1 C_2$$

From this equation, we can see that the SNR will increase for increased transmit power, antenna gain, and beam width. The SNR will decrease with increasing noise power and with longer wavelength. These five parameters are used for comparing the relative sensitivity of two radars. The discussion on SNR relevant to the specific dual polarization hardware is deferred to the section on hardware analysis as the receiver noise is not strongly dependent on wavelength difference of this magnitude.

Although we have left transmitter power and system noise in this equation, recall that we are initially interested in the SNR difference caused only by the wavelength difference between the test radars. The next section will discuss the effects of antenna gain, beam width, and wavelength alone. The transmitter power, receiver gain, and system noise will be addressed in the hardware analysis section.

Data Analysis – Wavelength Effects

The antenna gain is given in decibels relative to an isotropic radiator, and thus the ratio is simply the difference in the provided values. Because the gain affects both transmit and receive paths, the difference is doubled (g^2). When comparing two systems, the ratio of the two-way antenna gain of the test system to the two-way antenna gain of a standard system provides the relative gain between the systems. In our case, KCRI will be the standard and KOUN will be the test system. Thus, the antenna ratio is:

$$g \text{ Ratio(dB)} = 10 \log\left[\frac{g \text{ (KOUN)}}{g \text{ (KCRI)}}\right]$$

The relative antenna gain is negative because the KOUN antenna gain is lower than the antenna gain of KCRI due to the wavelength differences. The values used in the wavelength analysis are explained in a detailed discussion on the antenna gain provided in the section on hardware analysis. Testing and analysis indicate that the baseline and dual polarization antenna versions exhibit nearly identical performance, with the dual polarization modification being designed by ARA Seavey to match the baseline as closely as possible. The differences herein are due to wavelength alone and not the result of any significant difference in the design. This analysis uses values derived from solar scans that were in use at the time of data collection.

The difference in the beam widths is also considered a ratio and is handled similarly to the transmit power ratio:

$$\theta_1 \text{ Ratio}(\text{dB}) = 10\log\left[\frac{\theta_1 \text{ (KOUN)}}{\theta_1 \text{ (KCRI)}}\right]$$

Again, because this term includes both azimuth and elevation (assumed equal) for the beam width, the dB difference value is doubled. In this case the ratio is positive because the KOUN beam width is wider than KCRI due to wavelength differences. Actual values of the data comes from historic data provided by Andrew Canada [2], and more recent testing done at the ARA Seavey range in Cohasset MA [5]. For KCRI operating at 2995 MHz, radar channel 2, the Andrew data indicates the beam width is about 0.9 degrees. The recent Seavey tests on the baseline yielded results of approximately 0.89 to 0.92. This analysis uses a value of 0.90 for KCRI beam width. For the dual polarization antenna on KOUN operating at 2705 MHz, the Seavey data indicates the beam width is 0.95 degrees.

The wavelength difference is treated in the same manner, as a ratio:

$$\lambda \text{ Ratio}(\text{dB}) = 10\log\left[\frac{\lambda \text{ (KOUN)}}{\lambda \text{ (KCRI)}}\right]$$

Even though the KOUN wavelength is longer, and thus a positive ratio, the term is in the denominator and thus is treated with a negative sign. It is also doubled as the term is squared. The wavelength used in the analysis is calculated from the equation:

$$\lambda = \frac{c}{f}$$

where λ = wavelength, f = frequency, c = speed of light (3.0 X 10^8 m/sec)

Table 1, Data Analysis – Inherent Sensitivity Difference

Parameter	KCRI	KOUN	KCRI/KOUN	Comments
g	45.16	44.6	-1.12	Gain in dB, two way difference, KCRI and KOUN gain from sun check derived adaptation data, KCRI advantage
θ	0.90	0.95	+0.46	2 times beam width in dB (Az and El), KOUN advantage
λ	10.02	11.09	-0.88	centimeters, difference converted to dB, KCRI advantage
Total			-1.48	Total difference is -1.5 dB, KCRI advantage (more sensitive than KOUN)

This analysis indicates that when observing sensitivity differences between the test radars, KCRI and KOUN, an adjustment of 1.5 dB is required to account for the inherent advantage of KCRI due to the wavelength. Note that the largest source of error in the above analysis are the estimates of the antenna gains. This aspect is addressed in the hardware section below.

Hardware Analysis

The major hardware difference affecting sensitivity between the baseline WSR-88D and the dual polarization version is caused by the necessity of splitting the available transmit power into two channels, Horizontal and Vertical. The available power for either of the channels is reduced by a minimum of one half, or 3 dB. There are some additional insertion losses associated with the power dividing hardware and these are discussed below. The second major difference is in the antenna. L3 and Baron selected ARA Seavey for the source of the new orthogonal mode transducer and dual polarization feed assembly rather than acquiring the hardware from the original antenna manufacturer, Andrew Canada. This created the potential for changing the inherent performance of the legacy antenna. However, range testing and subsequent field observations on the KOUN radar indicate the performance is similar to the legacy baseline. The third change is in

the receiver. L3 Baron designed a completely new receiver subassembly and this also is analyzed below.

Figure 1 is a simplified overview of the relevant hardware components. The primary factors affecting sensitivity are the available transmitter power at the antenna input (antenna port), the antenna gain (referenced to the antenna port), and the receive path losses from the antenna port to the input of the first amplifier, typically a Low Noise Amplifier (LNA). These factors, along with the system noise level, target size, and range related losses, establish the signal to noise (SNR) ratio at the input to the LNA.

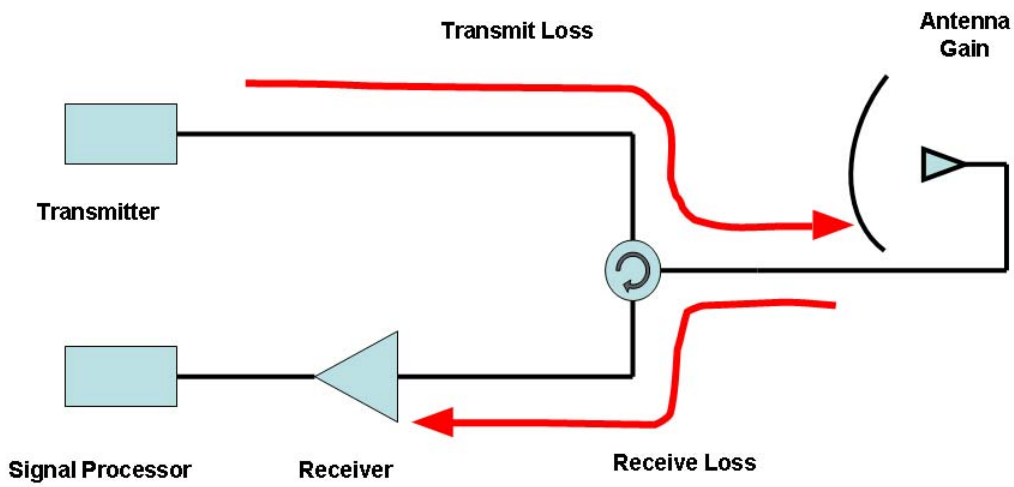

Figure 1 - Hardware Overview

Increases in the transmit and receive path losses and decreases in antenna gain will reduce the available SNR at the receiver input and thus reduce sensitivity. Larger system noise levels, including noise generated by the receiver, will further reduce usable SNR and reduce sensitivity.

The following are sections devoted to the transmit path loss, receiver performance, and antenna analyses.

Transmit Path Loss Analysis

The peak transmitter power available at the input to the antenna (P_t) is in units of kilowatts. For the relative sensitivity analysis, a ratio of the peak powers is converted to decibels:

$$P_t \text{ Ratio}(\text{dB}) = 10\log\left[\frac{P_t\ (\text{KOUN})}{P_t\ (\text{KCRI})}\right]$$

The term is negative when determining the ratio of sensitivity between KCRI and KOUN because the KOUN peak power available at the antenna port is lower than the power available at the KCRI antenna port. The primary reason for lower peak power available in the analysis is that each of the ports (H and V) have, at best, half of the supplied power available. Because the reflectivity, velocity and spectrum width moments are derived from just one channel (H typically), the sensitivity is reduced. The available power at the antenna port, H or V is further reduced by insertion losses inherent with the power dividing hardware and the associated calibration and monitoring devices.

Figure 1 depicts a simplified block diagram of the transmit path losses for both the baseline WSR-88D and the modified dual polarization prototype.

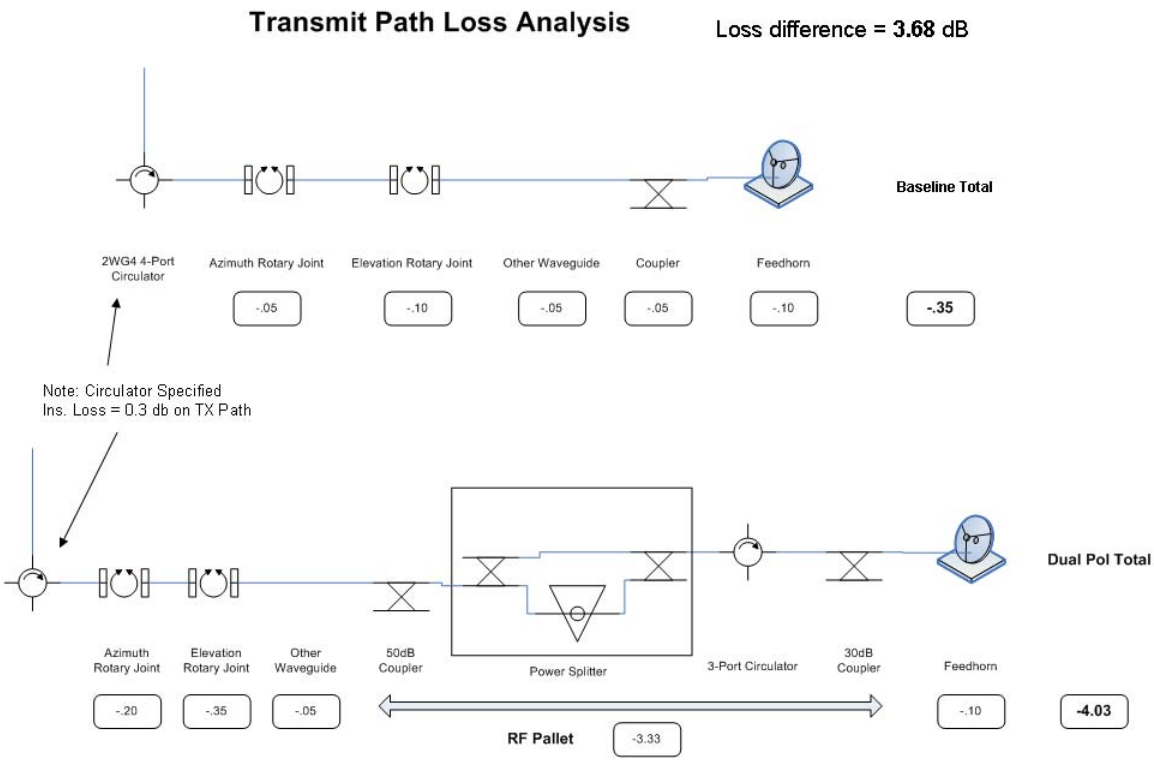

Figure 2 - Transmit Path Loss Analysis

Note that the overall transmit path loss for the baseline WSR-88D is -.35 dB. This does not include contributions from the 4 port circulator, but includes the two rotary joints, miscellaneous waveguide sections and a test coupler. Data on individual component insertion losses comes from typical values measured at field sites for the WSR-88D network. (personal communication, ROC engineer Alan Free).

The dual polarization total transmit path loss is 4.03 dB. This does not include the loss from the baseline 4 port circulator that the L3 Baron team chose to leave in place. The loss of this device is 0.3 dB and overall system loss could be reduced by replacing it with a waveguide section. However, the waveguide section would be of custom design, and would contain bended sections as the flanges do not line up. The expected insertion loss of such a custom section would reduce the savings resulting from replacing the circulator and thus the net reduction in loss would be on the order of 0.1 dB. It is not likely to be cost effective to replace this item for performance reasons alone.

The dominant loss remaining in the dual polarization version is from the so called "RF Pallet". This is the component that performs the power division and also provides test signal outputs and separates the receiver and transmitter signal paths. The total loss from the transmitter power input to the Horizontal channel output is only 3.33 dB [6].

The total transmit path loss difference between the baseline WSR-88D and the dual polarization modification is 3.68 dB. This difference directly contributes to sensitivity differences.

Receiver

The differences in the receivers are depicted in Figure 3.

For the receivers, the critical factors are the receive path loss from the antenna to the LNA, and the front end noise levels. Gain is less important and is mostly set to establish proper operating limits at the input to the digital IF receiver (RVP8 IFD input). As seen in Figure 3, the dual polarization version has a slightly lower receive path loss (0.17 dB) and the noise established at the input is about 1 dB lower than the noise of the baseline WSR-88D. Front end noise will vary considerably with environmental changes and a difference of 1 dB does not necessarily always translate into a reliable sensitivity improvement. However, all other parameters being equal, a lower receiver noise level will provide somewhat of an improvement.

The dual polarization receiver has an additional feature which improved performance. In this design, the RF signal is mixed down to IF in the antenna mounted electronics. This is accomplished by sending the stabilized local oscillator (STALO) signal up the tower and to the receiver via a rotary joint. Sending IF down the heliax cables rather than the RF signal can improve system noise performance and reduce transmission line loss.

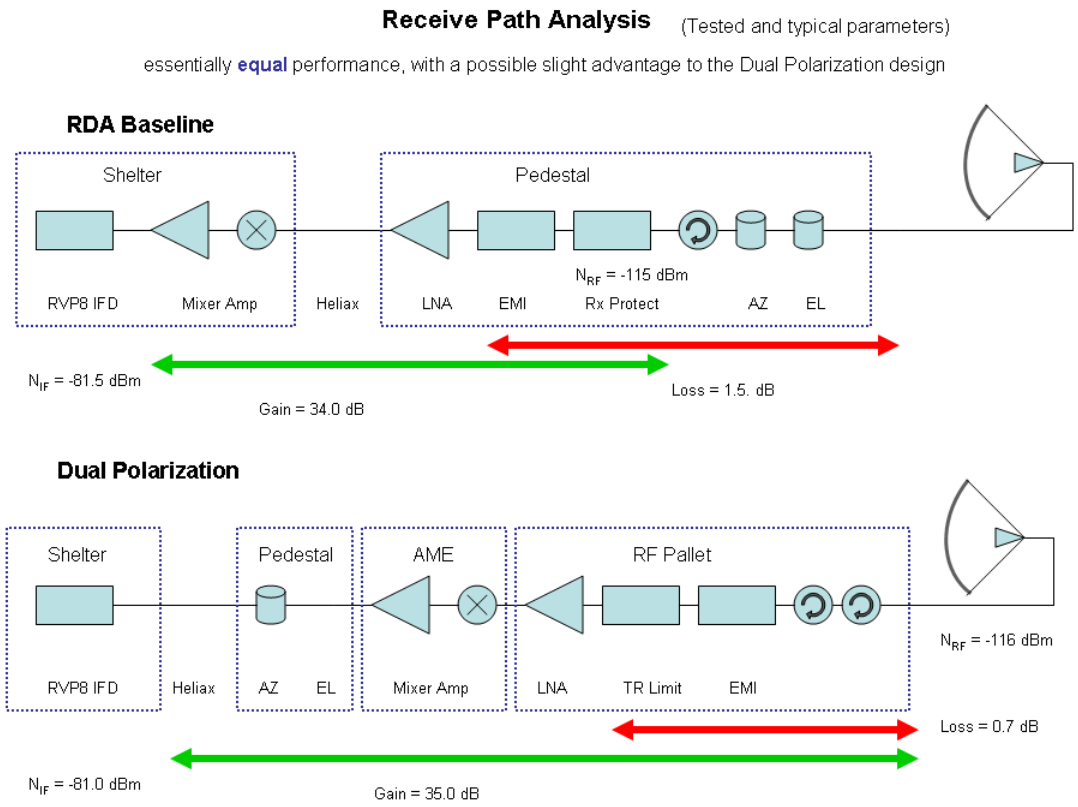

Figure 3 - Receiver Difference Analysis

The conclusion is that the receivers are not very different. The validity of this conclusion is supported by the fact that both receivers provide an analog Intermediate Frequency (IF) signal to the Sigmet RVP8 IF Digitizer (IFD). The analog to digital converters (A/Ds) in the IFD are the limiting factor for both dynamic range and quantization noise contributions. The signals from both receivers should have similar gain and dynamic range characteristics because the full scale power and dynamic range capacity of the IFD are fully utilized in both designs. The primary difference in the two analog receivers is with regard to noise characteristics.

The dominant factor in sensitivity difference remains the transmit path loss, which includes the loss of 3 dB due to the power splitting. This leads to the conclusion that the sensitivity difference should be in the vicinity of 3.7 dB. If the differences are observed to be lower than 3.7 dB, they can be explained by considering the better performance of the dual polarization receiver.

Antenna Analysis

Antenna Data from Seavey Range Tests:

The government provided a baseline WSR-88D antenna to L3 Baron for testing at the ARA Seavey range in Cohasset MA. Seavey conducted baseline measurements on the WSR-88 configuration on January 27, 2009. The results are summarized in Table 1. Seavey then modified the antenna using an orthomode transducer, feed horn, waveguides, and a mechanical mounting strut of their own design and manufacture. Seavey tested this assembly on the same range on March 26, 2009. The Seavey configuration included the so called "vertex feed" mounted at the reflector vertex. This vertex or "Shadow" feed was a test fixture under consideration for installation on all modified antennas. Testing at KOUN in Norman OK during the summer of 2009 indicated the vertex feed was unsuitable for system calibration and monitoring and this has since been deleted from the design. However, testing of configurations with and with out the vertex feed indicate it had no measureable effect on antenna performance.

Table 1 - Baseline WSR-88D antenna performance, Seavey range tests

Test	2.7 GHz	2.8 GHz	2.9 GHz	3.0 GHz
Gain dBi[1]	45.23	45.8	45.14	45.8
Beam width, degrees[2]	0.94	0.94	0.89	0.92

Notes: (1) Seavey charts indicate gain is "H – H", assume horizontal port as this is the only one for this configuration, (2) beam width charts titled "E-Plane" presumably indicating E plane wave guide orientation for the power sensor.

The baseline data indicates that there were issues in the testing. The gains and beam widths do not accurately reflect antenna theory, even when considering the reported range accuracy of 0.2 dB. It is likely there was a problem with the reflector, the assembly, or even external interference for at least two of the frequency dependent test points. The Seavey range is located near the coast of Massachusetts and S band interference from marine radars has been observed.

Table 2 - ARA Seavey modified antenna performance, Seavey range tests

Test	2.7 GHz	2.8 GHz	2.9 GHz	3.0 GHz
Gain dBi[1]	44.67	45.15	45.20	46.10
Beam width, degrees[2]	0.95	0.94	0.90	0.86

Notes: (1) Seavey charts indicated gain is "H Port", (2) beam width charts titled "E-Plane" presumably indicating E plane wave guide orientation for the power sensor.

The results from the ARA Seavey modified version competed in March 2009 were of improved quality and indicated the modified antenna meets all WSR-88D requirements.

Historical Antenna Data:

Because the Seavey range data from the baseline tests were problematic, this analysis focuses on historical data and on more recent solar scans for the gain of the baseline configuration.

During the development of the WSR-88D, Andrew Canada conducted several range tests on the antenna prototypes. Available data is from measurements conducted in 1985, 1988, 1990 and 1992 [2]. These data sets covered at least two feed configurations on at least three separate occasions. The two feed configurations were for linear horizontal and circular polarization. The most recent data is for the 1992 testing conducted for the final production version employing linear horizontal. There is considerable variation in the measured antenna gain reported from the various tests. However, the average measured gain follows a linear fit that is close to the theoretical derived gain. The average measured and derived gains are approximately equal at mid band and lie approximately within 0.1 dBi at the upper and lower ends of the band. This data is summarized in the 1992 Operational Support Facility (OSF) report, "Calibration of the WSR-88D" by Dale Sirmans [2]. This summary has been verified by reviewing the test reports supplied by Andrew Canada as delivered by Unisys. Table 3 summarizes the gain and beam width data for the base line WSR-88D using measured average values.

Table 3 – Andrew Measured Average – Baseline WSR-88D Antenna

Test	2.7 GHz	2.8 GHz	2.9 GHz	3.0 GHz
Gain dBi	45.49	45.71	45.95	46.17
Beam width, degrees	0.97	0.94	0.91	0.89

Table 4 presents the gains from all three sources; baseline from historical and Seavey range data, and the Seavey version from range data.

Table 4 – Antenna Gain Summary

Test	2.7 GHz	2.8 GHz	2.9 GHz	3.0 GHz
Baseline WSR-88D Andrew data average	45.49	45.71	45.95	46.17
Baseline WSR-88D, Seavey data	45.23	45.80	45.14	45.80

Polarimetric – Seavey data, one test, E plane, H port	44.67	45.15	45.20	46.10
Mean of all Seavey tests, Polarimetric version (H port)	44.624	44.930	45.432	45.700

In addition to the historical Andrew range data and the Seavey range data, ROC engineering has examined sun scan derived antenna gains for KCRI. A chart summary of antenna gain test data, including recent sun scan estimates as of early April, 2010 is shown in figure 4:

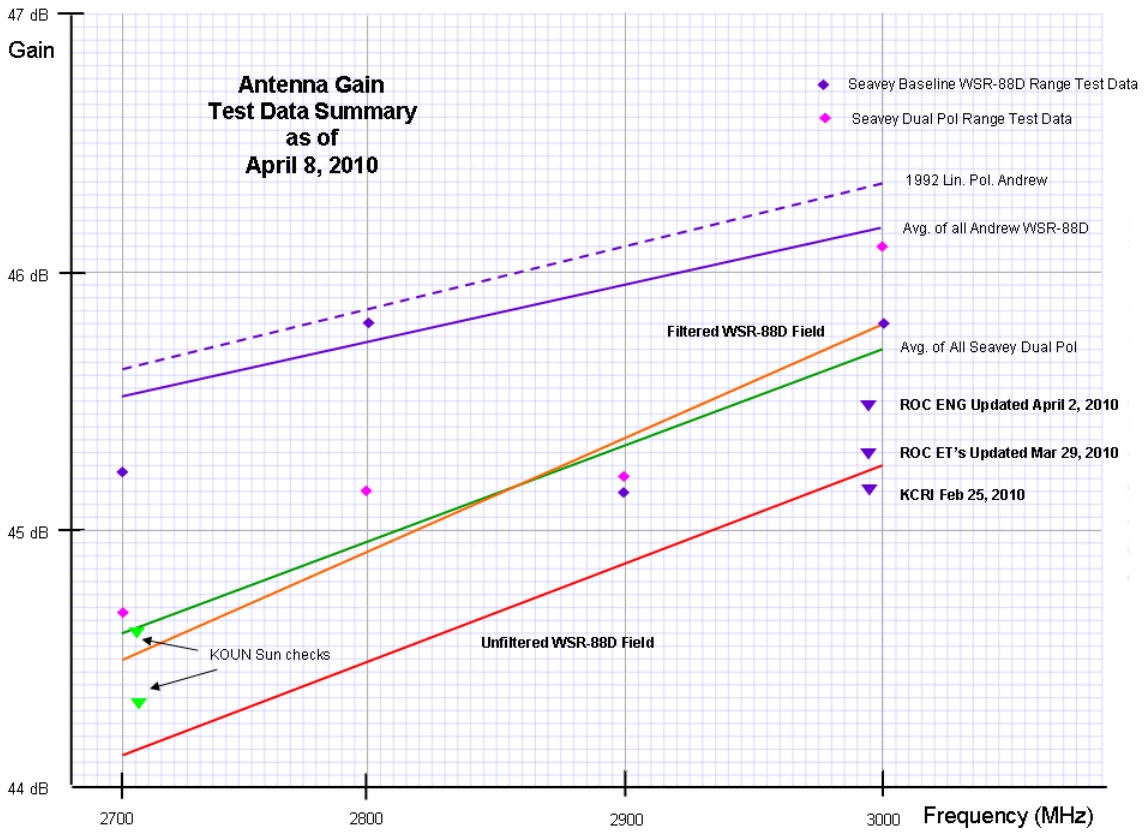

Figure 4 Antenna Gain Summary

Figure 4 contains all relevant gain data. The horizontal axis is the operating frequency over the allotted band (2700 to 3000 MHz) and the vertical axis is the antenna gain in Decibels Isotropic (dBi). The purple lines indicate the historical data from the Andrew testing with the dashed line indicating the most recent (1992) tests. The purple diamonds are the four data points taken at the Seavey range for the WSR-88D baseline. Note that the gain values for 2700 and 2800 MHz are significantly higher than the measured gains for 2900 and 300 MHz and the four data points do not have a good linear fit function. This is an indication of an error in the testing for the baseline version done in January

2009. The data points at 2900 and 3000 appear to be more correct. However, one also notices that these values are considerably lower than the data obtained by Andrew Canada.

The pink diamonds indicate the four data points obtained at the Seavey range in March 2009 for the dual polarization modification. There is still a bit of difficulty in fitting a linear function to these points, however they are better than the ones obtained in January 2009 for the baseline. Again, these gain values are much lower than the historical data from Andrew. Seavey engineers then conducted a series of tests over a two day period, repeating the gain tests and obtaining patterns through difference cuts of the reflector (vertical, horizontal, + and – 45 degrees). The mean of all the data obtained from these tests is the solid green line.

The solid red line (Unfiltered WSR-88D Field) represents the mean of gain data obtained from all WSR-88D field sites during the Open RDA installation. Note that this line indicates considerably lower gains than the Andrew or the Seavey tests. The solid yellow (Filtered WSR-88D Field) line represents the mean of gain data from the same data set, but with outliers removed. The outliers were those with obvious system calibration errors identified. Note that this quality controlled gain data set correlates well with the mean of all the Seavey range data. This correlation indicates that, in the mean, the modified Seavey configuration performs the same as the fielded baseline system.

The larger variations in the antenna data result from the difficulty inherent in gain measurements and from the three difference methods used. Andrew Canada obtained antenna patterns on their open air far field range at Whittby Ontario. These patterns were then digitized and the gain inferred mathematically using a proprietary software program. This gain data is for an antenna without a radome. The Seavey gain data was obtained from their open air far field range at Cohasset MA using the substitution method. This method employs a calibrated standard gain horn that is affixed to the antenna under test. Main lobe patterns are obtained simultaneously for both the antenna under test and the standard gain horn. The gain of the antenna under test is then inferred by comparing the main lobe patterns. The Seavey data also does not include radome effects.

The WSR-88D field data was obtained from solar scans. This is the only method available for fielded systems and has been shown to be sufficient when test parameters are carefully controlled, with a variance of 0.2 dB being possible [3]. The solar scans include the effects of the radomes. It is somewhat encouraging to note that the mean of all field tests, when properly quality controlled, matches well with the mean of all the tests conducted at the Seavey range. The radome can reduce gain by between 0.2 and 0.4 dB. This reduction is of the order of the variance expected between solar scans and the reported accuracy of the Seavey range (0.2 dB solar, 0.2 dB Seavey range).

The result of this analysis was that the engineering team decided to rely on current solar scans for obtaining the relative gains between KOUN and KCRI. This method provides a good comparison between the radars as the method is essentially the same. Any biases inherent in the solar flux reporting and software modeling processes will be the same for

each system. Other biases due to calibration may occur, but these can be controlled by the engineering team. The triangles, (green for KOUN, purple for KCRI) indicate some of the solar scan results.

Therefore the antenna gain data used in the section above for computing the wavelength dependent sensitivity reduction came from the solar scan reported data current with the meteorological data analyzed in the next section (45.16 dB for KCRI, 44.6 dB for KOUN in Figure 4).

Since the data collection effort, the ROC team and the L3 Baron team have adjusted the antenna gains after careful and repeated solar scans. These adjustments from more recent estimates of gain increase the difference in the gains between the two systems. The effect on this analysis would result in allocating more of a difference between the radars due to wavelength effects, perhaps to 2 dB or more. This would result in the conclusion that the sensitivity difference between the baseline and dual polarization versions is actually less than the 3.5 dB currently expected. If the new antenna gain estimates are correct, then the loss would be adjusted lower than the currently expected 3.5 dB. This would result in the conclusion that the dual polarization system exhibits better performance than described in this analysis and thus is not an issue.

Radar Performance Comparisons KCRI to KOUN

The test team continually collected data from both radars during the months of February, March and April 2010. Data from three cases are summarized here. These cases are:

- February 4, 2010
  - VCP11 – Light rain/big snow flakes mixed together 100s of feet off the ground

- February 26, 2010
  - VCP12 - Wet radomes, heavy wet snow near and over the radars. Lots of echoes within 80 nm of the radars. Radar volume start times 12 seconds apart.

- March 20, 2010
  - VCP212 - Cold Front, Isolated Convection, Wide Spread Snow, Strong SFC Winds
  - A strong upper level low was located in south central OK tracking eastward along the Red River. A surface cold front was located in eastern OK. Strong northerly surface winds throughout most of OK. Widespread snow, heavy at times, covered much of OK and northern TX. Isolated convective cells developed in south central OK near the upper level low.

Data from a winter precipitation case of February 4, 2010 is presented in the following section. Figures 5 and 6 show the 0.5 degree reflectivity for both radars.

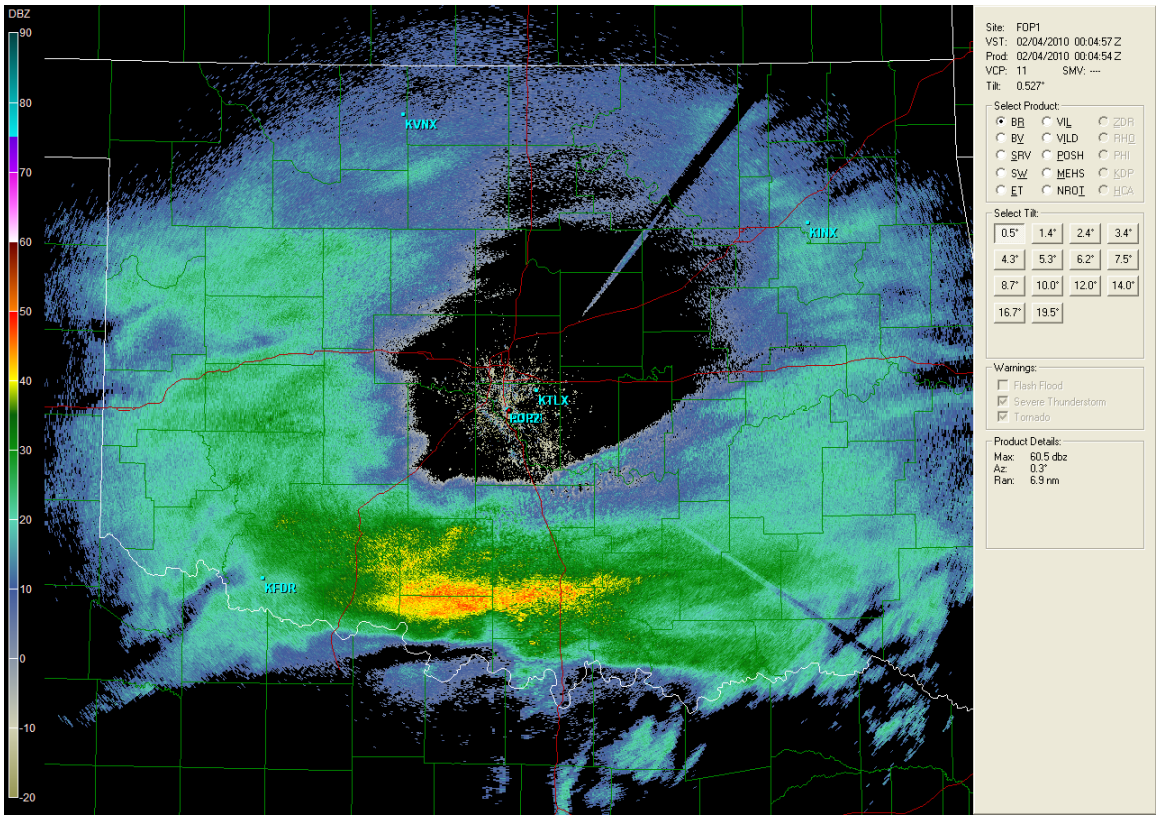

Figure 5 - Feb 4, 2010 KCRI

From the hardware analysis, there should be a 3.7 dB difference in sensitivity between the systems due to hardware. To this difference an additional difference of at least 1.5 dB must be allotted for wavelength effects. Thus the two systems should exhibit more than 5 dB of sensitivity difference and this difference is noted in the weather signal coverage differences seen in Figures 5 and 6.

The ROC teams quantitatively compared coverage between KOUN and KCRI using receiver time series replay and data bin counts. The teams reprocessed receiver time series data for KCRI with various levels of SNR thresholds. By increasing the SNR threshold in the KCRI data, the apparent weather signal coverage is reduced. By comparing data bin counts, the teams were able to determine how much additional SNR censoring was needed to reduce KCRI's sensitivity to a level equivalent to the sensitivity of KOUN. In most cases, this process resulted in an estimate of raw sensitivity differences of between 4 and 6 dB, with the most commonly observed value being approximately 5 dB. These results are not covered further herein, but can be obtained from the ROC Data Quality Team briefings and minutes.

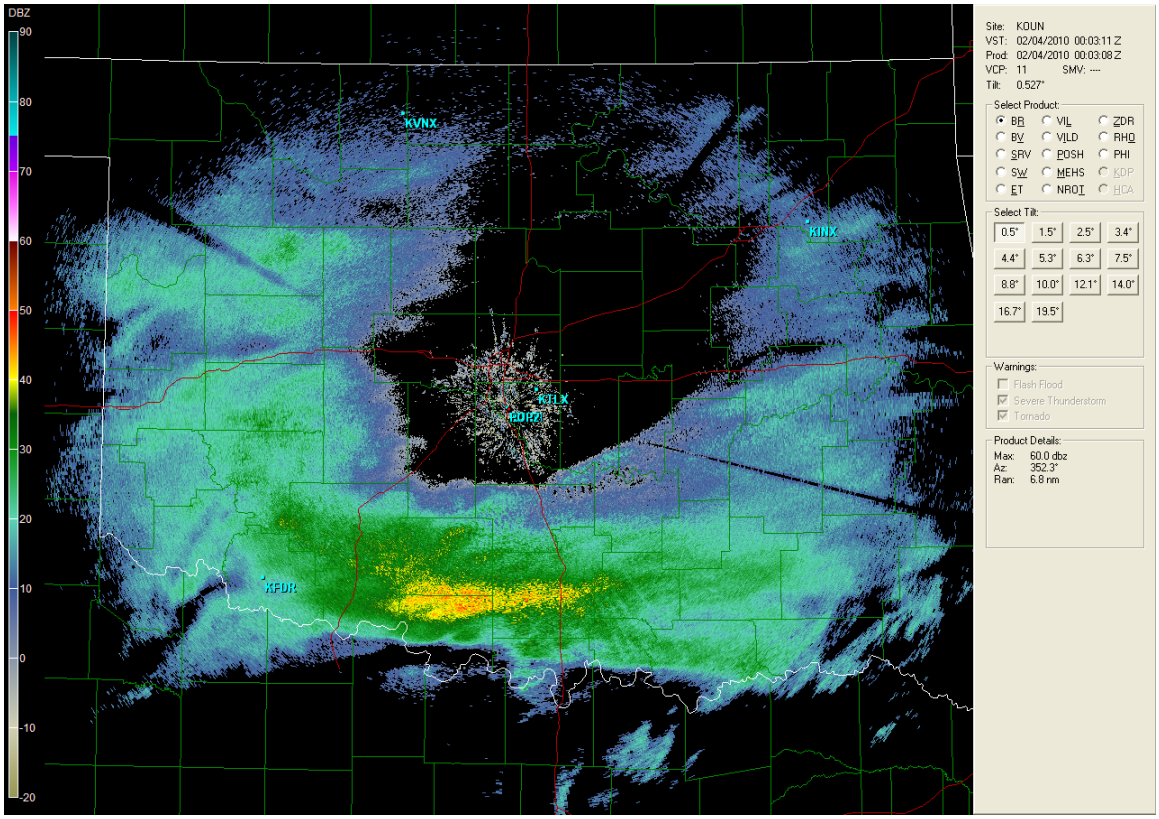

Figure 6 - Feb 4, 2010 KOUN

The Engineering Branch Team then analyzed the SNRs for each radar on a radial by radial basis. This provided good insight into propagation and backscatter effects. A typical output of a single radial analysis is shown in Figure 7.

In this figure, the left panels present the SNRs and Reflectivities for each radar as a function of range for a single radial. The right panels present the differences in SNR's (upper right) and the differences in reflectivity's (lower right). Note the noisy characteristic of the differences in SNR and reflectivity for a single radial comparison. The mean difference is indicated by the red line. This mean is taken for the ranges that exclude the first 45 km. (The 45 km exclusion is done because both radars are configured to clutter filter all data bins from the radar out to a range of 45 km.) For this analysis, the team purposely excluded clutter filter effects. Note that for this randomly chosen radial, the SNR differences have a mean of 4.2 dB.

The individual radial plots exhibit high variance. This may be due to the small sample size, or the time differences between the scans. In order to increase the sample size and average out temporal effects, the team analyzed complete elevation scans by plotting the mean SNR and reflectivity differences for each radial around the full 360 degree scan. An example of this data product is shown in Figure 8.

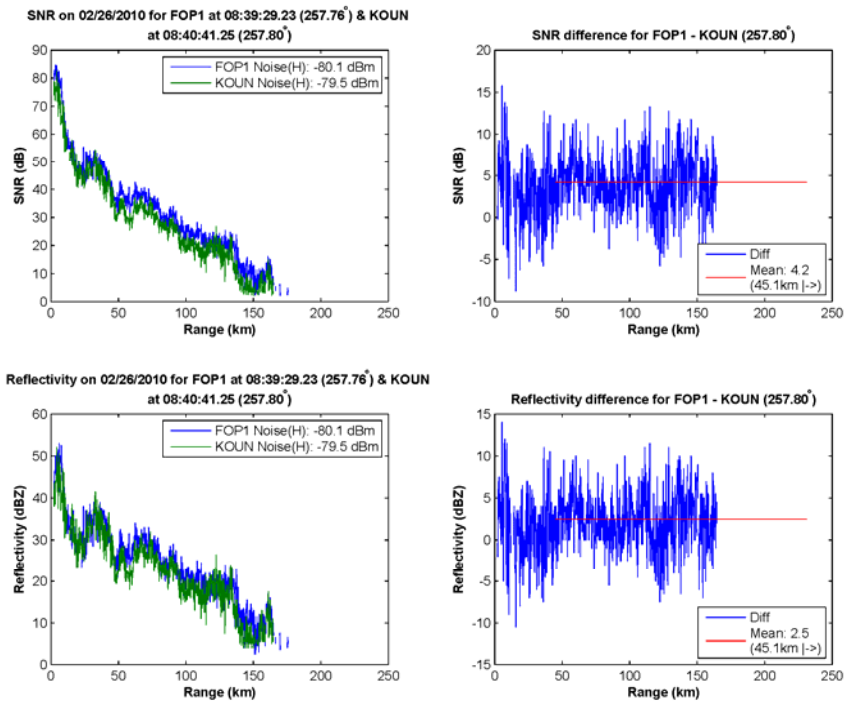

Figure 7 - SNR and Reflectivity Down a Single Radial

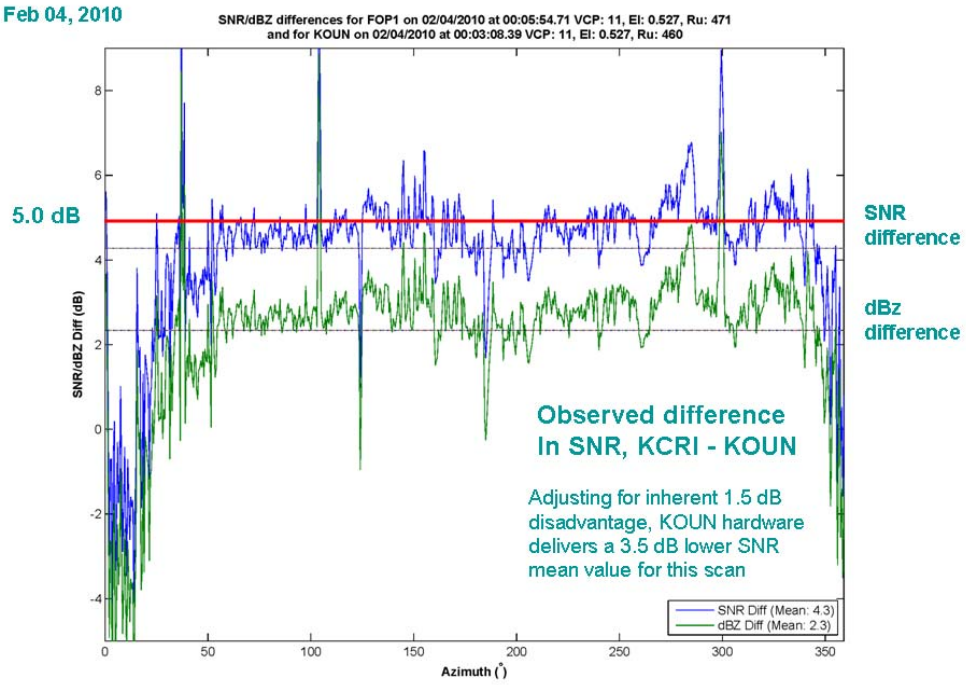

Figure 8 - Mean SNR and Reflectivity Difference, Feb 4, 2010

The team quickly learned how to interpret this type of plot, looking for evidence of sufficient signals and essentially "normal" propagation and scattering phenomena meeting the Rayleigh model assumptions. From this figure, the mean difference obtained by visual interpretation is around 5 dB. This excludes azimuths with obvious issues such as blockage or high variance due to insufficient signal.

Data from another case from February 26, 2010 is shown in Figures 9 and 10. These figures show the radar reflectivity for KCRI and KOUN. This was a strong mixed winter event with heavy snow near the radars. Note the high reflectivity values near the radars.

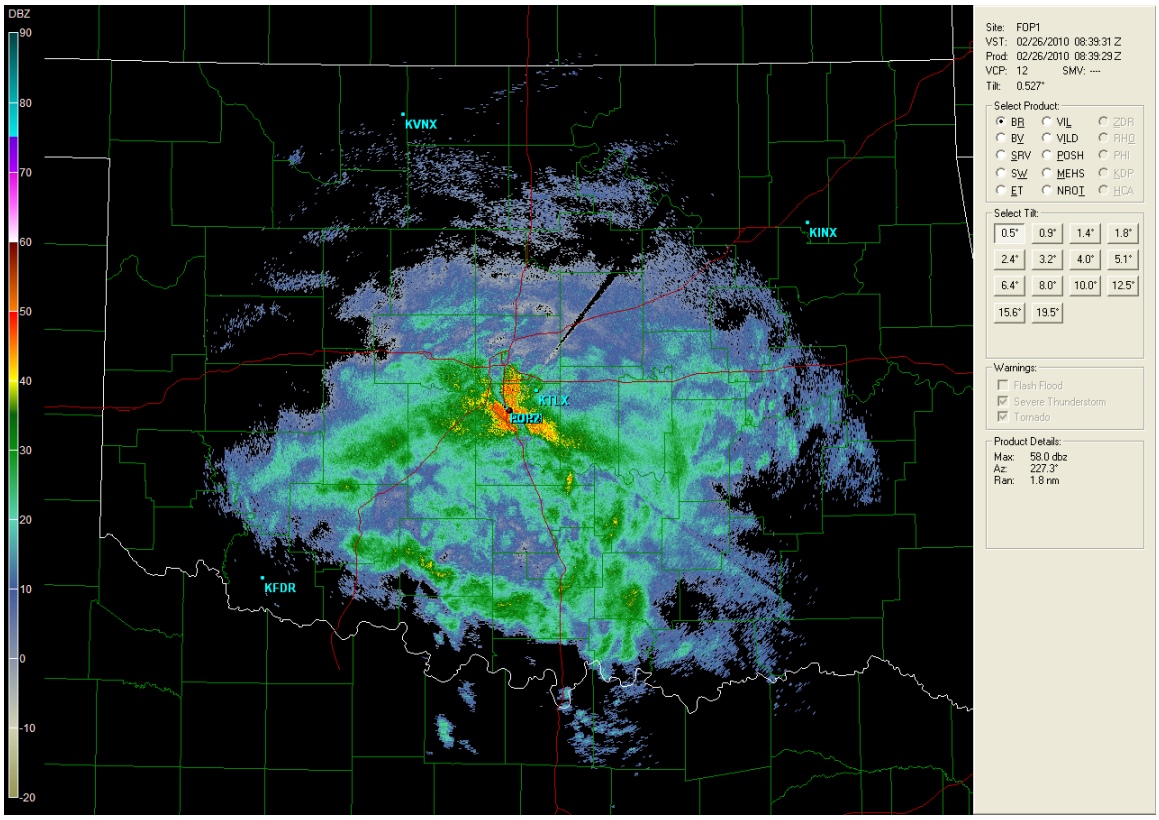

Figure 9 - February 26, 2010 KCRI

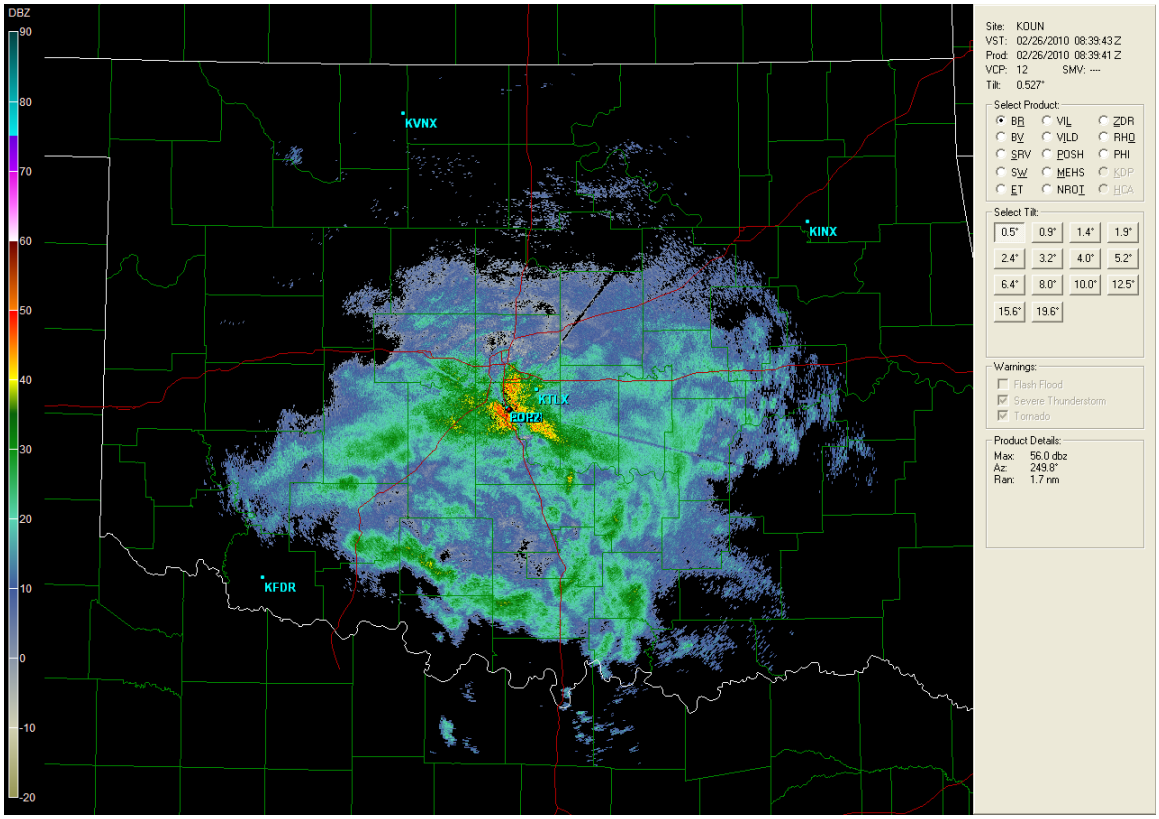

Figure 10 - February 26, 2010 KOUN

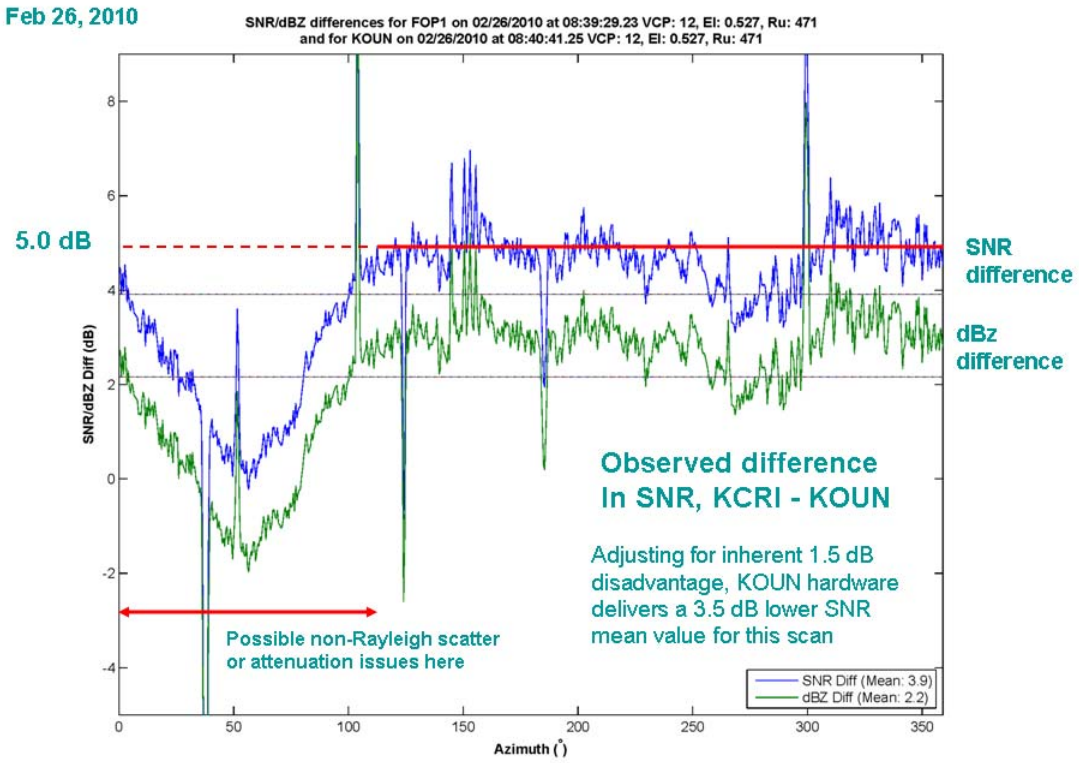

Figure 11 - Radial Mean SNR and Reflectivity, Feb 26, 2010.

The radial mean SNR and reflectivity plots are shown in Figure 11. Note the "odd" region between 0 and about 100 degrees where the SNR (and reflectivity) differences decrease. At about 50 degrees, the relative sensitivity between the radars is nearly equal, indicating KCRI was experiencing some sort of unexpected loss.

The team theorized that this sector could contain hydrometeors of a size to move KOUN out of the Rayleigh scattering region. Melnikov [4] recently reported on backscatter differences between these same two radars due to non-Rayleigh scattering issues. Specifically he indicted that reflectivity differences would be observed between these radars for clear air returns from insects and birds and from hail cores. The team also considered the possibility that one or the other or both of the radomes could have been covered in wet snow. The winds were coming directly from that sector; however, due to the blizzard conditions no one observed the radome conditions at the time.

The reason for the dramatic difference in the 0 to 100 degree sector was of interest, but not critical to an analysis directed at observing hardware performance differences. By excluding the 0 to 100 degree sector, the mean difference is observed to be, again, about 5 dB, and may actually be closer to 4.7 dB.

The third case analyzed is from March 20, 2010. Figures 12 and 13 present the reflectivity data for the 0.5 degree elevation scans.

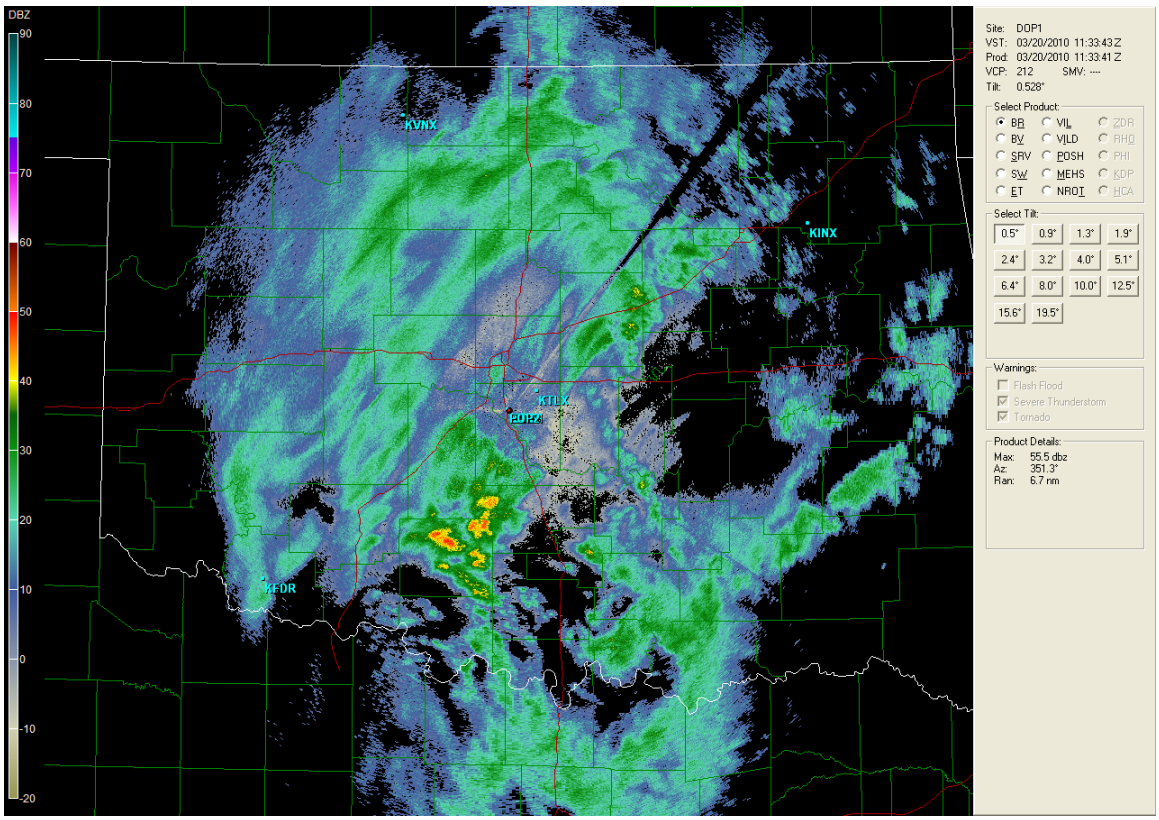

Figure 12 - KCRI Reflectivity March 20, 2010

This case resulted from a cold front passage. At this time there was rain and mixed phase precipitation to the south east of the radars, while snow was evident in the north and west sectors. This provides a mix of particle types with a range of scattering characteristics that may be observed differently by radars at difference wavelengths.

By examining the radial SNR and reflectivity mean plots of Figure 14, there is a distinct change in the SNR difference for the south east and north west regions. This may be caused by a backscatter difference due to non-Rayleigh scatter. The regions that appear to contain mostly snow exhibit a lower SNR difference. However, looking at the azimuths that are likely to be dominated by rain, the SNR difference again appears to be about 5 dB.

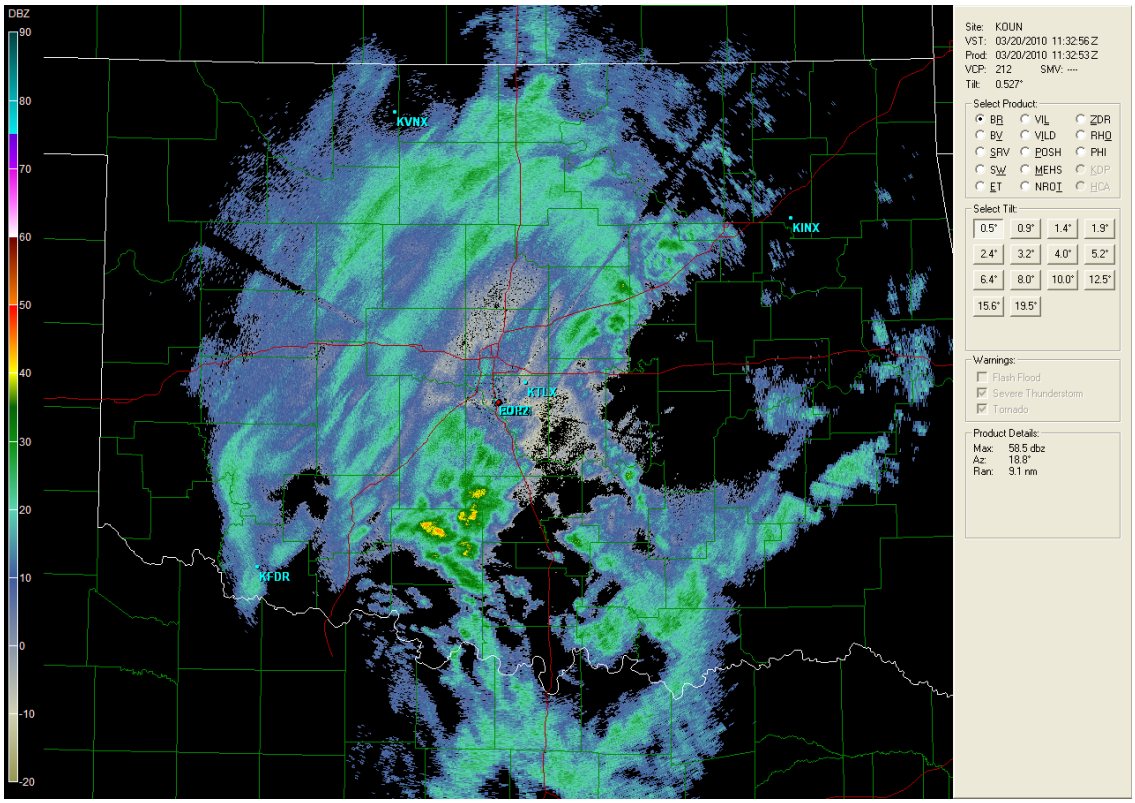

Figure 13 - KOUN Reflectivity, March 20, 2010

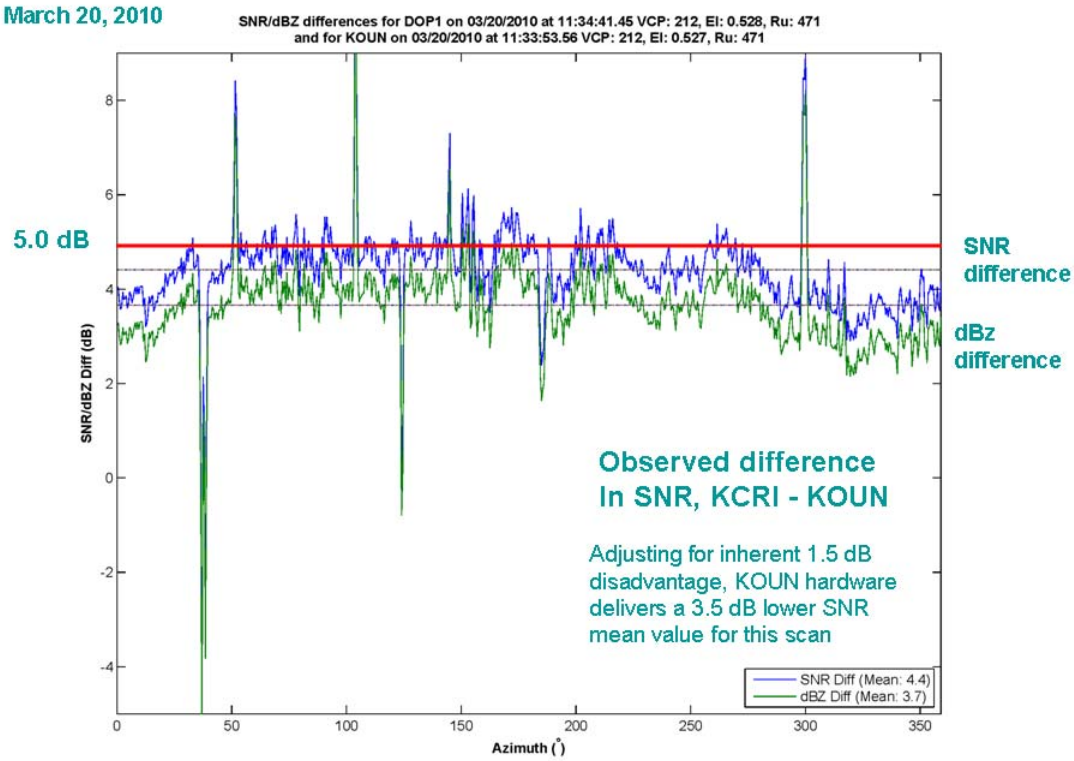

Figure 14 - Radial SNR and Reflectivity March 20, 2010

Examination of these three cases, along with ROC Engineering Branch and Applications Branch teams replay, threshold adjustment and bin count analysis, confirm that the raw sensitivity difference between the two radars is on the order of 5 dB. Accounting for the previously determined 1.5 dB difference due to the wavelength difference between KCRI Channel 2 and KOUN, the observed difference due to the dual polarization hardware is 3.5 dB. Allowing for some variation in production hardware performance and in uncertainty of the measurements, it is likely the typical loss for a field WSR-88D will be less than 4.0 dB.

Summary

This paper examines the expected difference between two test radars operating at opposite ends of the frequency band. It also presents the expected difference in sensitivity due to the dual polarization modification hardware. Finally it presents results of analysis of collected radar data to confirm theoretical calculations. The expected difference in the test radars due to wavelength alone is at least 1.5 dB. The expected difference due to the hardware is 3.68 dB. The sensitivity difference observed in radar data, corrected for wavelength and antenna gain effects, is 3.5 dB. The observed difference compares well to the expected difference provided by hardware design analysis.

This analysis concludes that the expected sensitivity loss due to the dual polarization hardware at a typical site will be less than 4.0 dB and may typically be 3.5 dB or less.

References

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Rick Rhoton, Centuria Corp. provided the radial SNR and reflectivity plots.

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