P2.16 WSR-88D ORDA ANTENNA GAIN AND BEAMWIDTH ALGORITHMS

Alan. D. Free*
SI International, Norman, OK

Nita K. Patel and Richard L. Ice, RS Information Systems, Inc., Norman, OK
Olen E. Boydstun, Radar Operations Center, Norman, OK

1 ABSTRACT

Accurate measurement of the WSR-88D Antenna Gain is vital in computing accurate Reflectivity of weather data. Proper calibration of the Open Radar Data Acquisition (ORDA) receiver path and noise test path is necessary to obtain accurate estimates of the WSR-88D antenna gain. This paper presents a discussion of the antenna gain calibration path, explains the algorithms used to compute antenna gain and beamwidth, presents the manufacturer's antenna gain and beamwidth measurements and provides actual field data from WSR-88D ORDA sites.

2 SUNCHECK BASICS

Antenna Gain is important to computing accurate reflectivity of weather data. In order to calibrate WSR-88D antenna gain, the sun is used as the data source. The source provides a stable, known input because its location in space is known, its size is known and its output power can be measured.

In the WSR-88D, the Suncheck calibration routine determines three parameters: antenna positioning offsets, antenna beamwidth, and antenna gain. Suncheck Subtest 1 computes antenna offsets and beamwidth. Suncheck Subtest 2 calibrates Antenna Gain, which encompasses the gain of the antenna dish and microwave losses.

Both subtests require accurate time and site location information. The Open Radar Data Acquisition (ORDA) upgrade to the WSR-88D added a GPS unit for accurate system time. The site latitude and longitude can also be obtained from the GPS unit. These values are stored in each site's adaptation data.

* *Corresponding author address:* Alan Free, SI International, 2227 W. Lindsey St., Suite 1500, Norman, OK 73069; e-mail: Alan.D.Free@noaa.gov

Suncheck Subtest 2 requires two additional inputs, solar flux and accurate antenna pointing. Solar Flux data is obtained from one of the Solar Observatories, typically the Dominion Radio Astrophysical Observatory in Penticton, Canada. This observatory measures flux at 2800 MHz, falling near the middle of the 2700-3000 MHz band of the WSR-88D.

Pointing accuracy is verified by Suncheck Subtest 1 prior to execution of gain measurement. The correction offsets, limited to +/- 0.3 degrees in both azimuth and elevation, are stored in the site's adaptation data. Inaccurate pointing will result in low gain measurements since the algorithm for computing gain assumes that the scan for data collection passes through the center of the sun.

The WSR-88D Antenna Gain measurement is not simply a measurement of the antenna dish gain. As Figure 1 shows, the WSR-88D Antenna Gain includes all the shared transmit and receive parts not measurable with internal test signals. The Antenna Gain measurement uses sun flux, the radar's location, the beamwidth of both the sun and the radar, and losses from the radome and waveguide from feedhorn to Receiver Protector Input.

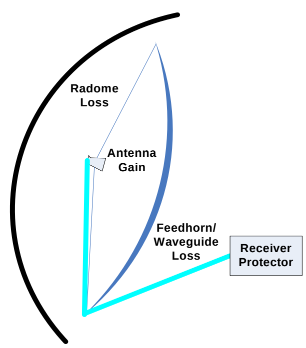

Figure 1: Antenna Gain Components

The results from Suncheck are used to calculate dBZ0, the calibration value derived from the weather target radar equation (see Equation 1). dBZ0 includes Antenna Gain (G) and Antenna Beamwidth (θ). Gain measurements assume transmit and receive antenna paths are identical, and the beamwidth measurement assumes that the horizontal and vertical beamwidths are identical. Since dBZ0 is used directly in the computation of reflectivity (see equation 2) for a given input power signal, the values computed in the WSR-88D Suncheck routines directly influence the system reflectivity values.

$$dBZ_0 = 10\log\left(\left(\frac{2^{10}\times\ln(2)}{\pi^3\times c}\times\left(\frac{10^{-3}\times(10^3)^2\times(10^{-2})^2\times10^{18}}{10^3\times\left(\frac{\pi}{180}\right)^2\times10^{-6}}\right)\right)\times\frac{\lambda^2}{G^2\times\theta^2\times\tau\times|K|^2}\times\frac{1}{P_T\times L_t}\times\frac{1}{L_r}\times\frac{N}{L_d\times g}\right) \quad (1)$$

$$dBZ = 10\log\frac{P_R - N}{N} + 20\log(R) - aR + dBZ_0 \quad (2)$$

3 MANUFACTURER DATA

During the development and installation of the initial WSR-88D, the antenna and pedestal assemblies of the WSR-88D were tested and qualified through a series of formal tests. These tests were conducted by the antenna manufacturer, Andrew Corp. and the NEXRAD prime contractor, Unisys in the late 1980's and early 1990's.

3.1 Test Range Details

The Andrew range tests used similar test configurations. The range consisted of the WSR-88D antenna mounted on a test tower on a three axis positioner. The tests were conducted using a remote signal source located 17,000 feet away using programmable frequency generators and amplifiers. The WSR-88D test antenna was equipped with an appropriate test coupler which allowed connection of microwave receiving equipment. The couplers were located very near the antenna dish, minimizing the waveguide length between the feed and the coupler.

The system was equipped with appropriate servo position monitoring and power measurement and recording devices, all providing data to a custom pattern recorder.

This test configuration was used to obtain azimuth and elevation antenna patterns, including cross polarization patterns. Antenna gain, beamwidth and bore sight accuracy were inferred from the patterns using proprietary Andrew software utilities.

2.7, 2.775, 2.85, 2.925, and 3.0 GHz were used for beam width and sidelobe compliance tests. The 2.7, 2.85, and 3.0 GHz frequencies were used for gain calculations and cross polarization level tests.

3.2 Test Data

Andrew provided data on both the derived gain computed and average antenna gain measurements taken during range testing. These measurements are for only the antenna and do not include the radome, feedhorn and receiver protector losses.

A handful of sites were measured and compared to the theoretical values with the Original WSR-88D deployment. As can be noticed from Figure 2, there is a large variance between actual site data and the theoretical computation.

Similarly, Figure 3 provides the theoretical antenna beamwidth distribution. The beamwidth was derived from aperture geometry, efficiency and illumination.

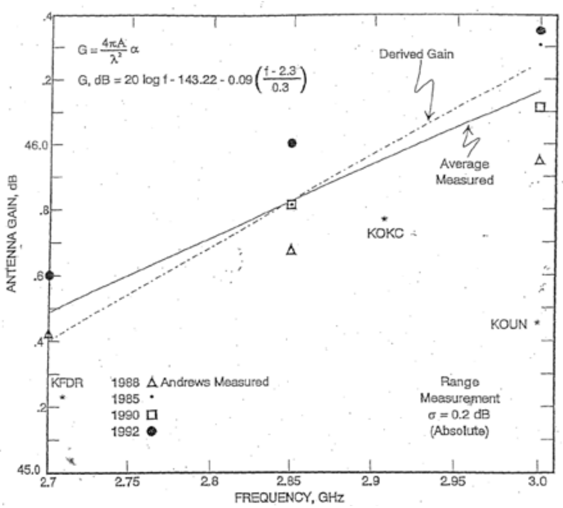

Figure 2: Andrew Antenna Gain Data

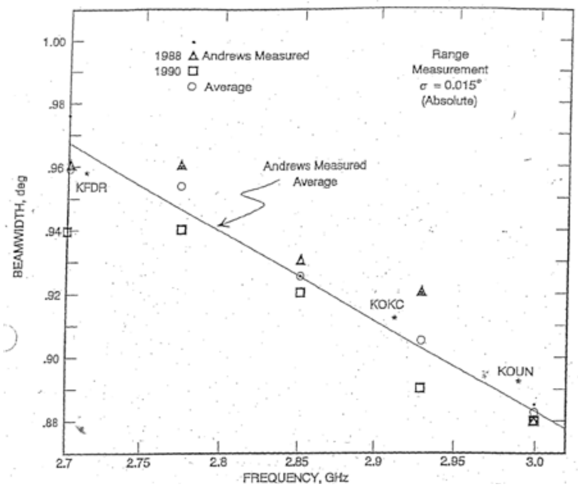

Figure 3: Andrew Beamwidth Data

4 SUNCHECK PROCEDURES

In the WSR-88D, the system provides offline software routines to compute antenna beamwidth and system gain. Suncheck Subtest 1 determines the antenna beamwidth and absolute antenna positioning by scanning through the sun in both azimuth and elevation. The general routines are outlined in the next sections.

4.1 Suncheck Subtest 1

The suncheck routine incorporates a NOVAS algorithm to compute sun location relative to the radar based on latitude, longitude, date and time. If the sun is below 8° or above 50°, the test will abort. Otherwise, the radar will be positioned to the sun's computed elevation and azimuth angles. Then data will be collected while the antenna scans from -3° to +3° in azimuth.

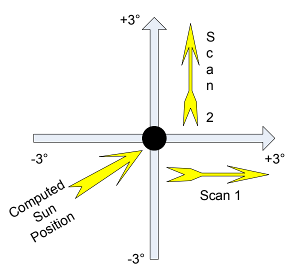

Figure 4: Sun Scan

The software then computes the mean receiver noise level by positioning the antenna away from the computed center of the sun, at azimuth angle of (computed_az -3°). The noise level (N_m) value is used to determine a noise threshold (N_{th}) 3 dB above the computed noise level. All data points between the noise floor and the noise threshold are discarded.

After thresholding the data, the peak power (N_p) is computed. A power cutoff (P_c) point is established 5 dB below the peak. Any data below the peak cutoff power is discarded. If fewer than 2 points remain after any of these operations, the test is aborted.

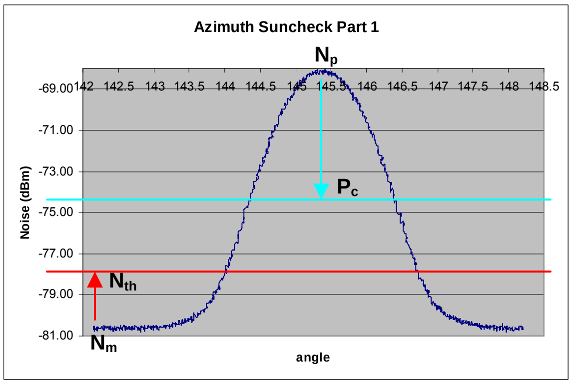

Figure 5: Suncheck Data Thresholds

The final step before fitting a parabolic curve to the data is to smooth the data. The smoothing algorithm simply compares each data point to adjacent points. If the data point is outside of +/- 3 dB from the adjacent points, the center point is replaced with the average of the two adjacent points.

Finally, the smoothed data is fitted with a parabolic curve ($Ax^2 + Bx + C = 0$) to compute the center location for antenna positioning.

After the azimuth scan is completed, the same process is repeated in elevation. The final elevation data is used to compute the system beamwidth.

$$BW = \sqrt{[\theta_{observed} - 0.1505 * \phi^2]} \qquad (3)$$

Where:

Variable	Definition
BW	Computed Beamwidth
$\theta_{observed}$	Beamwidth computed based on parabolic fit to data (N_p - 3 dB)
ϕ	Angular optical diameter of the sun

While Suncheck Subtest 1 verifies pointing accuracy of the antenna, Suncheck Subtest 2 measures the antenna gain. Correct antenna gain measurement is critical because reflectivity is proportional to two times Antenna Gain.

Therefore, a 1dB error in antenna causes a 2dB error in Reflectivity.

4.2 Suncheck Subtest 2

Suncheck Subtest 2 execution assumes:

- Accurate calibration of and correct adaptation data values for the entire receiver
- Accurate antenna pointing
- No external interference
- Consistent sun flux level, i.e., no solar flares or excessive solar activity
- Dry radome, i.e. not icy or wet

Any problems with the system can result in invalid system antenna gain measurements; therefore causing incorrect dBZ0 calibration.

Suncheck Subtest 2 prompts the user for the current solar flux since the system has no means to collect this information automatically. The flux can be entered as a single value, or as a pair of values. Typically a single value at 2800 MHz (from the Penticton Observatory) is used. The system software corrects the 2800 MHz reading for the actual site frequency with Equation 4.

$$S_f = (\alpha \times S_{10} + \beta)(f - 2800) + S_{10} \qquad (4)$$

Where:

Variable	Units	Definition
S_f	Solar Flux Units	Flux density at required frequency
S_{10}	Solar Flux Units	Flux density at 2800MHz
f	MHz	Frequency
α	None	0.0002
β	None	-.01

Measured Sun Noise Temperature is based on four measurements:

- Noise **away** from the sun (Blue Sky Noise) with calibrated Noise Source **off**
- Noise **away** from the sun (Blue Sky Noise) with calibrated Noise Source **on**
- Noise **on** the sun with calibrated Noise Source **off**
- Noise **on** the sun with calibrated Noise Source **on**

Equation 5 is used for Expected Sun Noise Temperature. Differences between the original WSR-88D software computations and ORDA software computations are identified in the equation variable definition table.

$$T_C = \frac{G * \lambda^2 * sfu * (10^{-22})}{4\pi * 2 * B} \times \frac{10^{\frac{RML}{10}}}{\left[1 + 0.18 * \left(\frac{\theta_S}{\theta_3}\right)^2\right]^2} \times \frac{1}{DC} \qquad (5)$$

Where:

Variable	Definition
G	Current Antenna Gain converted to ratio from dB in adaptation data
λ	Wavelength
sfu	Solar Flux Units as reported by Observatory (typically Penticton) ORDA SW compensates for site frequency
10^{-22}	Convert sfu to watts
4π	Related to antenna gain
2	Correction for single polarized solar flux
B	Boltzmann's Constant
RML	Receiver Microwave Loss in dB from antenna to receiver protector, from adaptation data
θ_S	Angle subtended by sun ORDA uses radio sun value instead of optic sun value
θ_3	Antenna 3dB beamwidth, from adaptation data
DC	Distance correction for earth-sun ORDA SW uses different algorithm

Equation 6 is used to compute the Noise Temperature of Noise Source injected into system.

$$T_N = 290\left(10^{\left(\frac{Noise_{source} + Noise\_Path}{10}\right)} + 1\right) = 290\left(10^{\left(\frac{ENR}{10}\right)} + 1\right) \qquad (6)$$

The Noise Temperature pointed away from the sun (at Blue Sky) is computed with Equation 7. Using the results from the Blue Sky Noise Temp computation, the Sun Temperature is computed with Equation 8.

$$T_R = \frac{\left(T_N - T_A \frac{P_N}{P_A}\right)}{\left(\frac{P_N}{P_A} - 1\right)} \qquad (7)$$

$$T_S = \frac{\left(T_N - T_R\left(\frac{P_{N2}}{P_S} - 1\right)\right)}{\left(\frac{P_{N2}}{P_S} - 1\right)} \quad (8)$$

Where:

Variable	Definition
T_A	Blue Sky Antenna Noise Temperature measured at Receiver Front End
P_A	Power Level at IFD when pointed at blue sky
T_N	Temperature of Noise Source at Receiver Front End
P_N	Power Level at IFD with Noise Source turned on pointed at blue sky
T_S	Sun Temperature, what we're looking for
P_S	Power Level at IFD when we're pointed at the sun
P_{N2}	Power Level at IFD with noise source on pointed at the sun
T_R	Receiver Noise Temperature pointed at Blue Sky
$Noise_{source}$	Noise Power Level from Noise Source, in dB
Noise_Path	Loss from Noise Source to Front End Injection, in dB
ENR	Excess Noise Ratio, Noise Power Level injected into Front End, in dB

To determine the measured system gain, the Computed and Measured Noise Temperatures are compared as shown in Equation 91.

$$G = 10 \times \log\left(\frac{T_c}{T_s}\right) \quad (9)$$

For accuracy and stability, it is recommended that the antenna gain not be updated from one measurement, but that at least five measurements are made to ensure stability. Ideally, multiple measurements would be taken on different days at different elevations and azimuths to ensure stability since many parameters affect antenna gain.

5 RESULTS (NORMAL)

Figures 6 and 7 show data collected from a typical, calibrated, operational site. From the power computed as the antenna is scanned across the sun, measurements can be made for azimuth boresight offset, elevation boresight offset and beamwidth.

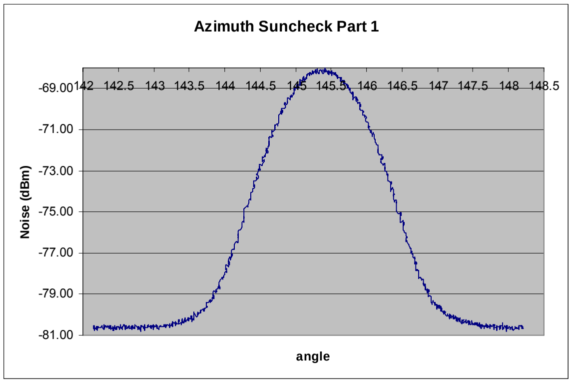

Figure 6: Typical Azimuth Scan

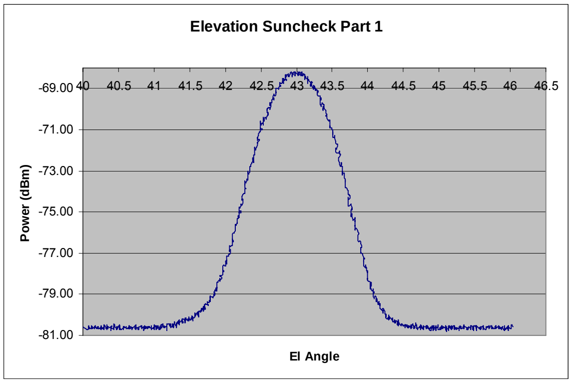

Figure 7: Typical Elevation Scan

5.1 Operational Fleet Data

Figure 8 shows Antenna Gain values for 65 sites analyzed to have the fewest known site calibration errors. It shows that the measured gain is generally lower than the Andrews estimated gain, and it also shows a large standard deviation for the antenna gains. Generally, the Andrews calculated gain is the maximum gain of which the system is capable. Any problems with waveguide, with the radome, or with the antenna shape would have higher losses and therefore reduce the gain.

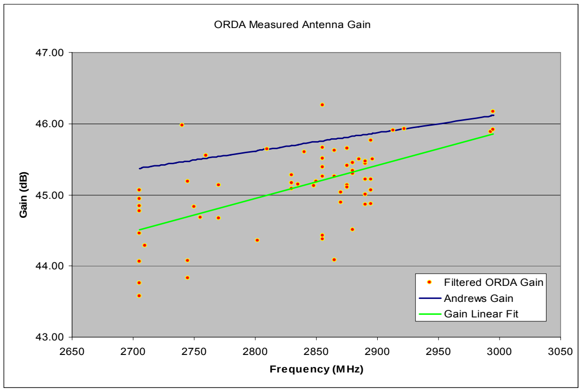

Figure 8: Measured Antenna Gain

The data for beamwidth (Figure 9) also shows a fairly large standard deviation. The beamwidth is typically measured higher than predicted, and the slope of the fitted line is a lot flatter than Andrew predicts.

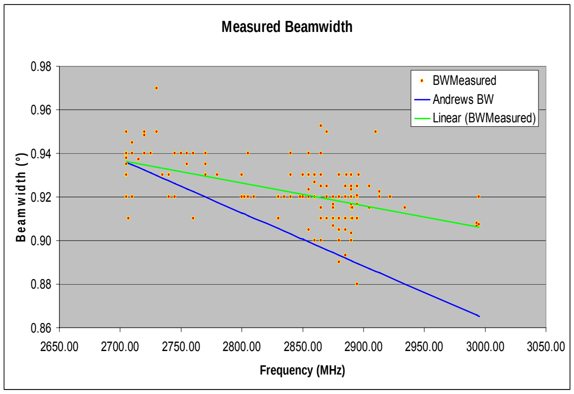

Figure 9: Measured Beamwidth

6 RESULTS (ANOMOLIES)

Data collected by ORDA logs during execution of Suncheck can help to identify problems. Some problems that can affect Suncheck results include external Noise, erratic encoder readings, or bad encoder slip rings. These problems can cause incorrect or unreliable position measurements.

Figure 10 shows a site experiencing large external interference spikes. In this particular case, suncheck is not able to run correctly because the noise spikes go up to -63 dB. The Power cutoff (P_c) is set to 5 dB below this peak value. Although the scan shows that most data is very smooth and a good fit could be achieved by simply removing the noise spikes, the software routine fails due to the fact that most of the data falls below P_c and is deleted.

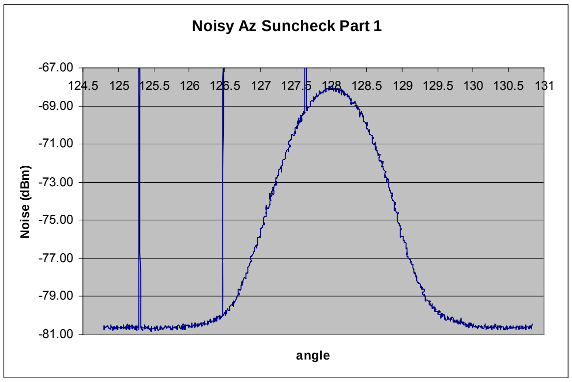

Figure 10: Noise Spikes in Sun Scan

Another problem can be seen in figure 11. The top image, the azimuth scan, did not have any problems. However, the second, elevation scan has noticeable problems. In this case, the elevation position was not being maintained correctly or the elevation encoders were reporting inaccurate position information. The more likely result is inaccurate elevation data due to problems with slip rings.

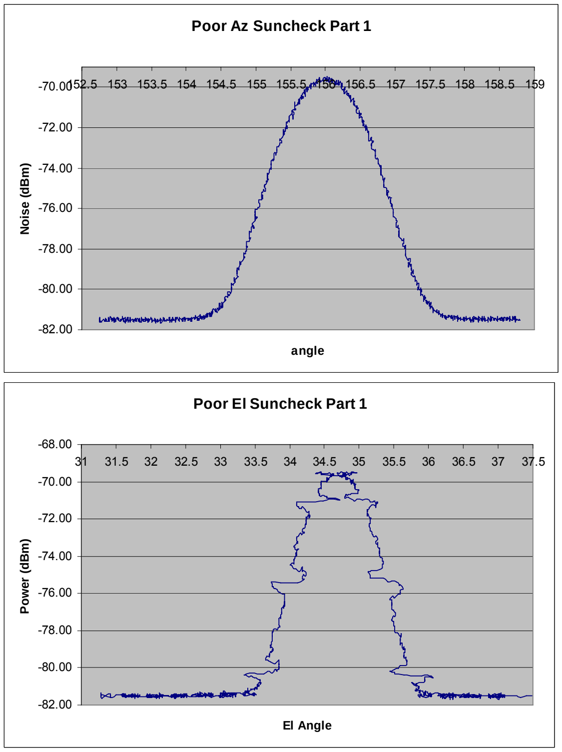

Figure 11: AZ & EL with faulty EL encoders

7 RECOMMENDATIONS

The Suncheck scan data provides much useful information for the field technicians in identifying problems such as external interference, large antenna alignment offsets and invalid data from encoders.

Although the current Suncheck routine provides much valuable data, improvements can be made. The following is a list of recommendations for improvement:

- Produce graphical representation of scan data to user (currently data is simply logged in a system log)
- Use the computed goodness of the parabolic fit to recommend acceptance or rejection of system antenna gain measurements
- Automatically average multiple system antenna gain measurements
- Increase number of required data points from 2 to 100
- Measure beamwidth only after antenna position offsets have been applied
- Tighten CW path and Noise path accuracy to 0.25 dB before allowing Suncheck execution
- Check system health and recommend rejection of system antenna gain measurements based on Noise Temp estimate differences

8 CONCLUSIONS

Suncheck accurately measures position of the antenna and computes critical parameters for the radar equation. As a result, system problems will manifest themselves in the Suncheck outputs, particularly system antenna gain. Using the sun is currently the only method for measuring the radome loss, antenna gain, and feedhorn to Receiver Protector Loss.

Antenna gain measured in Suncheck Subtest 2 is critical to accurate reflectivity measurements. The current Suncheck routines work well with certain assumptions, but an accurate calibration is difficult to achieve and difficult to verify. System antenna gain is susceptible to any problems in the receiver, and the entire receiver system must be accurate for a good antenna gain to be measured. Any inaccuracies in antenna gain are doubled in Reflectivity errors.

9 REFERENCES

Free, A., Heck, A., and Patel, N., 2005: NEXRAD Open Radar Data Acquisition (ORDA) Receiver Calibration, 21st International AMS Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology

Free, A., Patel, N., and Heck, A., 2004: ORDA Internal Report – ORDA System Calibration

Frush, 1984: Using the Sun as a Calibration Aid in Multiple Parameter Meteorological Radar, 22nd Conference on Radar Meteorology

Jim, G., and Free, A., 2004: ORDA Internal Report – ORDA Receiver Path

Operational Support Facility, 1992: Internal Report – Calibration of the WSR-88D

Patel, N., Free, A., Jim, G., 2005: NEXRAD Open Radar Data Acquisition (ORDA) Receiver Characteristics, 21st International AMS Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology

Pratte and Ferraro, 1989: Automated Solar Gain Calculation, 24th Conference on Radar Meteorology

Sirmans, D. and Urell, W., 2001: ROC Internal Report – Measuring WSR-88D Antenna Gain Using Solar Flux

Sirmans, D., 1992: ROC Internal Report – Calibration of the WSR-88D

Tapping, Dominion Radio Astrophysical Observatory: Antenna Calibration Using the 10.7cm Solar Flux

Urell, W., 1999: ROC Internal Report – WSR-88D Super-Calibration Case History

Whiton, Smith and Harbuck, HQAWS: Calibration of Weather Radar Systems Using the Sun as a Radio Source