P3C.8 Radar Calibration Using a Trihedral Corner Reflector

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1. INTRODUCTION

Many useful methods for calibrating weather radars in the field and laboratory are summarized by Joe and Smith (2001) from presentations at the 2001 AMS Radar Calibration Workshop in Albuquerque, NM. Additional methods are described by Atlas (2002). Common external (full-system) calibration methods range from using metal spheres suspended from balloons to the use of solar radio emissions. Although the task is seemingly straightforward, it is challenging to devise methods that are accurate but not so difficult to conduct that they are impractical. The method used by NOAA's Environmental Technology Laboratory (ETL) for calibrating its scanning X-band and K_a-band radars is described in this article. The radars are described by Martner *et al.* (2001, 2002).

2. ETL's REFLECTOR CONFIGURATION

Whereas, ETL uses the sun's sky position to precisely adjust its antenna pointing angles, the available monitoring of solar emissions at X and Ka-Band is generally inadequate for power calibrations, unlike the case for longer wavelengths. Therefore, ETL uses a trihedral corner reflector and procedures similar to those described by Rinehart on the Albuquerque workshop CD for a dihedral reflector. This is a conventional external calibration approach, but some aspects of the ETL configuration are uniquely designed to minimize problems that often hinder or degrade sphere and reflector calibrations.

The metal reflector dimensions are 0.305 m along each orthogonal axis spine. The trihedral concentrates the reflected signal directly backward toward the transmitting antenna. It is mounted atop an unusually tall pole in order to position it well above the height of contamination from nearby ground clutter (Figure 1). The 25-m pole, purchased from a utility company, is made of wood, thereby reducing its contribution to the returned signal. It is located at the west end of the Erie-1 site in Colorado, which is home base for several ETL radars. The distance between the radar antennas and the pole is independently measured (nominally 0.475 km). At this range, the reflector is in or very close to the far field for these antennas, which are small compared to those of most S-band research radars. The reflector sits approximately 3° (a few beam widths) above ground and approximates a point target, subtending only 0.04 degrees of arc. There are no intervening trees or structures across this flat tract of land.

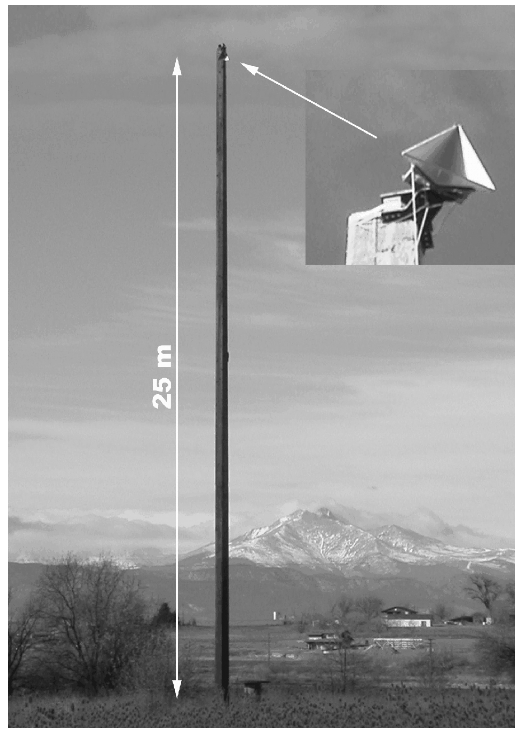

Figure 1. Photo of the trihedral reflector atop the wooden pole at the Erie-1 site. Longs Peak is in the distance and a close-up view of the reflector is in the insert at the upper right. The radars are located several hundred meters behind the camera.

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The configuration offers a convenient, stationary, elevated target of precisely known cross section and distance. It is mounted high enough on a minimally reflective support to produce a very strong return signal that is more than 25 dB above that of all clutter in the immediate vicinity. The radar is scanned very slowly across the reflector region in 0.1° increments of elevation and azimuth to produce a three-dimensional map of returned power. Data can be collected in range increments as fine as 7.5 m. At each range gate the scan data produce an azimuth/elevation map of returned power that serves as a reasonable representation of the antenna power pattern near the central beam axis. Application of the equation for returned signal power from a trihedral reflector and the point-target radar equation, as shown in the example in Section 3, allows the radar system gain and radar constant to be determined.

3. AN EXAMPLE CALIBRATION

The radar cross section of a trihedral reflector, σ (in units of m^2) is given by Levanon (1988) as:

$$\sigma = (4\pi a^4) / (3\pi\lambda^2) \qquad [1]$$

where a is the length of reflector axis (m) and λ is the radar wavelength (m). From various text books, such as Battan (1973), the radar equation for a point target is:

$$P_r = (P_t G^2 \lambda^2 \sigma) / ((4\pi)^3 r^4) \qquad [2]$$

where P_r is the received power (W), P_t is the peak transmitted power (W), G is the antenna gain (unitless) and r is the range of the target (m). The formula for the radar constant, RC (in dB), is also defined in various texts, including Rinehart (1997), as:

$$RC = 10\log((1024\ln(2)\lambda^2 10^{21})/(c\pi^3\tau P_t G^2 \phi\theta|K|^2)) \qquad [3]$$

where c = speed of light (m/s)
τ = pulse length (s)
ϕ = horizontal beam width (radians)
θ = vertical beam width (radians)
$|K|^2$ = refractive index of water

Unlike [2], the Probert-Jones beam pattern correction (ln 2) is used in [3] because theintended target now is scatterers distributed throughout the beam. Finally, this calibration is applied to future storm or cloud data to compute the radar reflectivity factor Z ($mm^6 m^{-3}$) or dBZ (=10logZ), using range-corrected power as:

$$dBZ = 10\log(10^3 P_r) + 20\log(0.001\, r) + RC \qquad [4]$$

The maximum returned power, P_r, is determined from the measurements obtained with the slow scans across the corner reflector. Then, application of equations [1] and [2] yields the gain, G (or the $P_t G^2$ term), which is then inserted into [3] to give the radar constant, RC.

A calibration of ETL's X-band radar is shown here as an example. In the case of the ETL radars, the signal returned from the reflector is so strong (equivalent to viewing a 70 dBZ hailstorm from half a kilometer) that it must be reduced to register within the receivers' dynamic range. For the X-band, this is accomplished using RF waveguide couplers. Figure 2 shows a constant-range map of returned power for a calibration conducted on June 8, 1999, shortly after an antenna from another radar was installed on this system. The pattern of power along the central axis is clearly apparent at this range gate where the maximum received power was observed. The spatial separation of the reflector's peak from the ground clutter signal of the lower elevation-angle sweeps is sufficient to present uncontaminated measurements in the region of the beam axis.

Figure 3 is a contoured cross section through these data at the same range gate where the maximum received power was located. The power is shown in dBm units. Accounting for the inserted waveguide coupler attenuation, P_r = -58.2 +58.9 = 0.7 dBm = 0.00118 W. The other fairly precisely known parameters for the radar, reflector, and test configuration were: λ = 0.0321 m, c = 2.99×10^8 m/s, $\tau = 0.75 \times 10^{-6}$ s, $|K|^2$ =0.93, a = 0.305 m, and r=474 m. Somewhat less accurately known were $P_t = 2.5 \times 10^4$ W, and $\phi = \theta$ = 0.7 deg = 0.0122 rad. These nominal beam widths checked nicely with the data of Fig.3 at the -6 dB level down from the peak for the two-way path.

Results of the calculations are G = 1.15×10^4 = 40.6 dB and RC = 83.7 dB. Probably the largest source of error is the inserted attenuation by waveguide couplers, which is estimated at ±1 dB. The combined beam width uncertainty adds another ± 0.5 dB. Other factors add only a small fraction of a dB uncertainty. In total, this provides radar reflectivity estimates with approximately 2 dB of uncertainty, if the procedures are executed carefully. This is suitably accurate for most, but not all, weather research applications. Although not as good as results expected from a sophisticated and expensive antenna test range, this method offers a convenient field check of the calibrations with good accuracy.

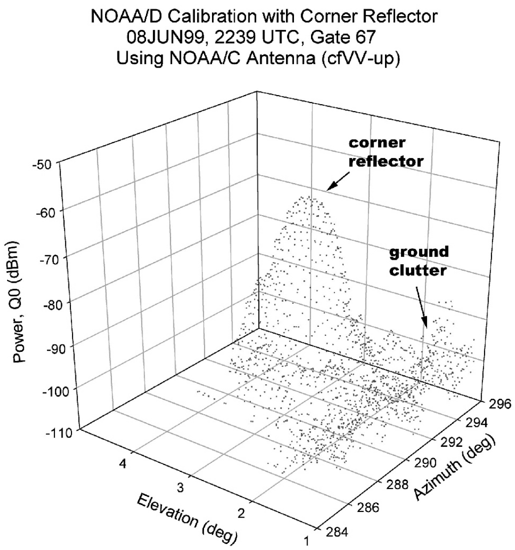

Figure 2. Pattern of power returned from the trihedral corner reflector vicinity at the range gate of maximum received power. The data are from a calibration of ETL's X-band radar at the Erie-1 site.

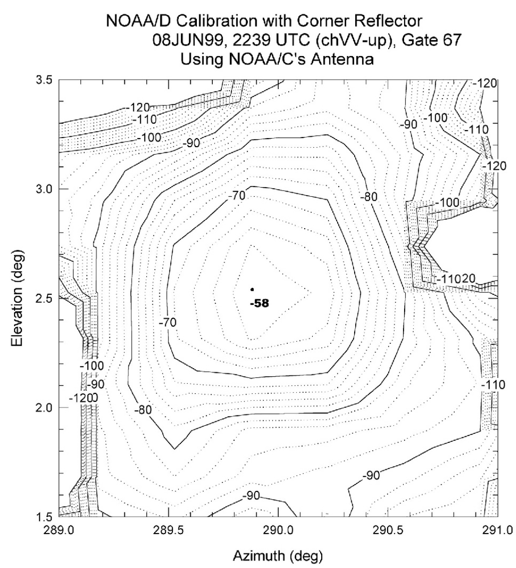

Figure 3. Contoured plot of received power (dBm) covering a 2° x 2° azimuth and elevation-angle region for the same range gate as shown in Figure 2.

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4. SUMMARY AND CONCLUSIONS

A metal trihedral reflector mounted on a very tall wooden pole provides a convenient means for calibrating weather radars that is simple, reasonably accurate, and relatively easy. As a target that is both elevated and stationary, it avoids difficulties commonly associated with trying to pass the radar beam axis exactly across a swaying metal sphere suspended from balloon, and signal contamination from nearby clutter that often degrades efforts to use reflectors mounted on shorter or more reflective supports.

Acknowledgments

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