WCR EXTERNAL CALIBRATION USING TRIHEDRAL CORNER REFLECTOR

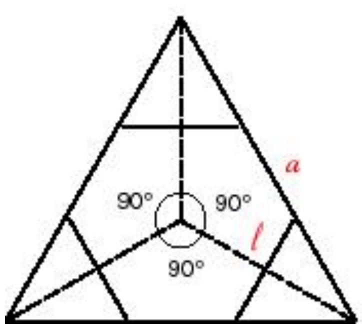
1. Measurement Setup

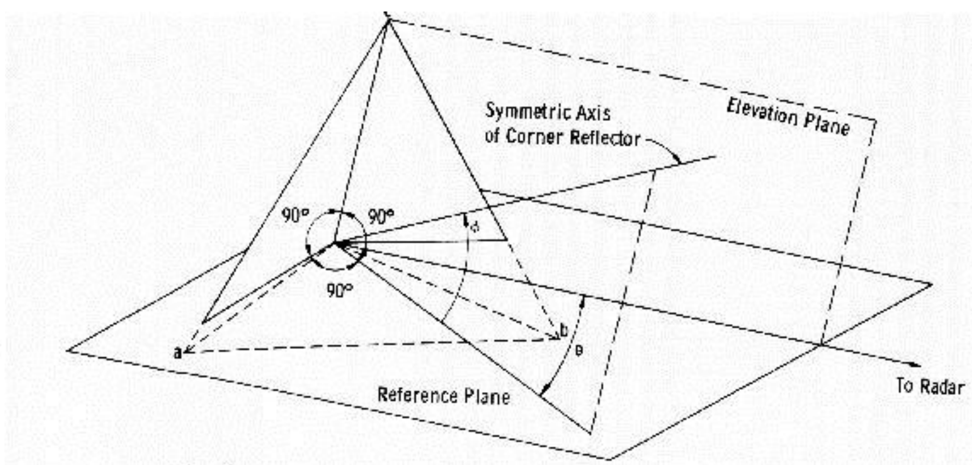
During filed experiments the WCR is calibrated from the Kingair aircraft using trihedral corner reflector. The radar beam is steered through the aircraft antenna fairing with a mirror reflector to point the beam vertically and a second reflector plate to point the beam horizontally. The second reflector plate has a fine precision scanning capabilities in azimuth and elevation. Analysis of the effects of the reflector plates on the corner reflector (CR) measurements show no significant loss (within the uncertainty of the measurements, < 1dB) and no noticeable distortion in the antenna pattern.

The corner reflector is mounted on a 15-foot cylindrical (1" diameter) aluminum pole and is usually located within 150 to 250 m from the radar. The pole is tilted approximately 20° away from the radar with respect to the vertical to minimize direct and multipath back reflection and is mounted on a tripod. Measurements of the tripod-pole setup without the CR show no less than 16 dB lower return. Whenever possible the location for the CR is chosen to additionally minimize possible multipath reflections (most often in grass areas and no closely located other targets). The CR is leveled and pointed toward the radar antenna manually and should be within a few degrees of the maximum return position.

2. Trihedral Corner Reflector Cross-Section.

A schematic front view of the CR and the geometry of CR measurements are shown in the figures below.





The calculated cross-section of the CR based on the equivalent flat-plate area (hexagon) is given by:

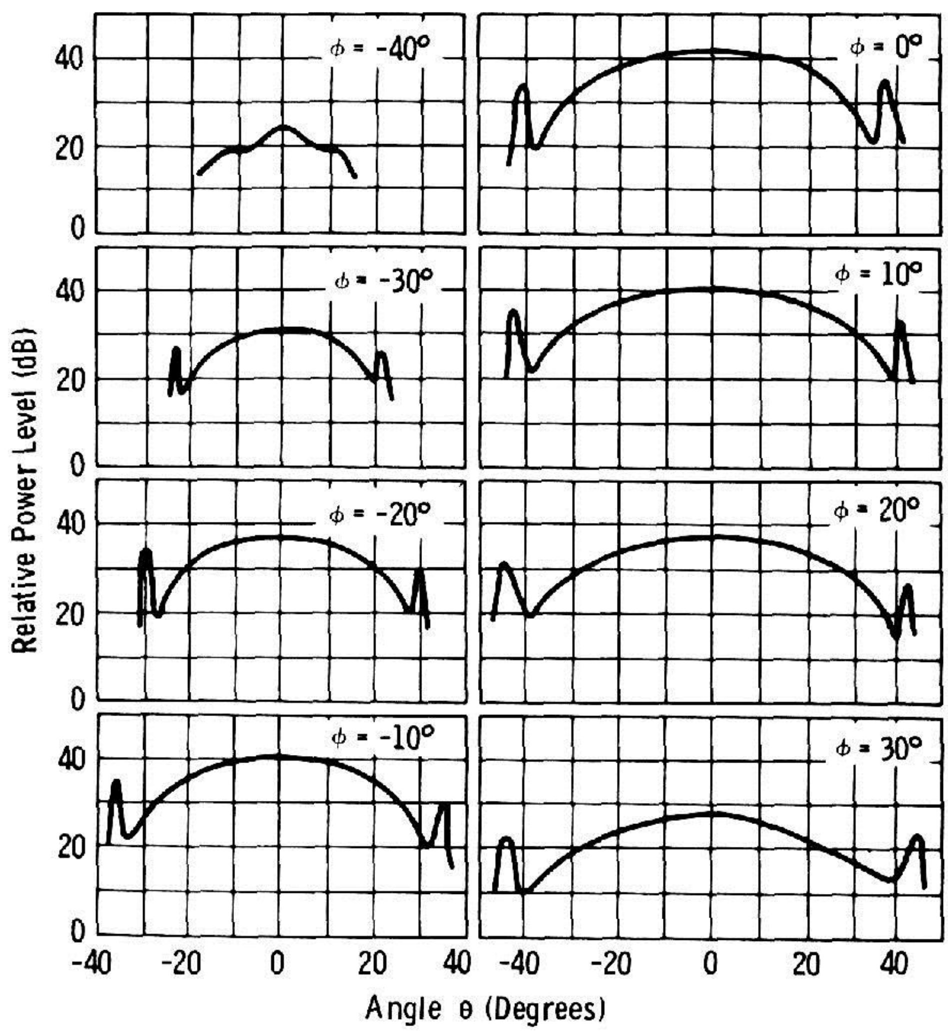
$$\sigma_{CR} = \frac{4\pi a^4}{3\lambda^2} = \frac{\pi l^4}{3\lambda^2} \quad [\mathrm{m}^2], \tag{1}$$

where l is the length of the CR side, a is the length of the edge of the CR aperture, and λ is the radar wavelength.

We use a commercially built corner reflector with $l = 0.036$ m ($a = 0.051$ m). The calculated cross section for this CR (assuming perfect orthogonality between CR sides) is

$\sigma_{CR} = 0.7057\ \mathrm{m}^2$.

Robertson (see Ulaby et al., Microwave Remote Sensing, v.2 p.775) measured the scattering pattern of a trihedral corner reflector. It is relatively flat and weakly dependant on φ and θ (see the graphics below). For φ and θ less than 10° the drop of σ_{CR} is less than 3 dB.



Also, according to Robertson even one degree deviation from the orthogonality of the CR causes more than 5 dB decrease in the measured CR cross-section in comparison with the calculated one.

3. Calibrating the Radar with the Corner Reflector.

Assuming accurate CR cross-section measurements we can calibrate the radar components from the antenna to the data acquisition output and use it as a single constant for absolute calibration of the radar reflectivity from weather targets. Since weather targets are distributed and the corner reflector is a point target this approach leaves the pulse shape and the antenna pattern unchecked. The antenna pattern should not change significantly in time and thus the measurements provided by the antenna manufacturer should suffice. The pulse shape is easy to check. Often it is sufficient to assume rectangular pulse shape and a Gaussian antenna pattern for the main lobe.

The monostatic radar equation for the CR is given by

$$P_{CR} = \frac{P_t g^2 \lambda^2}{(4\pi)^3 R^4} \sigma_{CR}$$

where, P_{CR} / P_t are the received/transmitted power [mW], g - antenna gain, including transmission loss (dimensionless), R - range to the CR [m], λ - radar wavelength [m].

Let define the following system constant:

$$C_s = P_t g^2 \lambda^2 \quad [\mathrm{m}^2\ \mathrm{mW}]$$

Assuming a constant transmitted power (see internal calibration section) and measuring P_{CR} we can determine the radar system constant provided that P_{CR} corresponds to the calculated CR cross-section (σ_{CR}) and is given in milliwatts (see internal calibration).

The system constant in dB then will be:

$$C_{s\_dB} = 30Log10(4\pi) - 10Log10(\sigma_{CR}) + 40Log10(R) + 10Log10(P_{CR}) \, .$$

After calculating the known quantities and expressing R in km (R_{CRkm}):

$$C_{s\_dB} = 154.49 + 40Log10(R_{CRkm}) + 10Log10(P_{CR}) \, .$$

The radar equation for a weather target (volume scattering) can be represented (Doviak & Zrnic, Doppler Radar and Weather Observations, 1993, p.75) by:

$$P_r = \frac{C_s}{(4\pi)^3 l^2 r^2} \eta \frac{\pi\theta^2}{8Ln(2)} \frac{c\tau}{2},$$

where, c is the speed of light, τ - pulse width, θ - half-power one-way beam width, l - one-way attenuation, r - range to the target, η - reflectivity. In the above radar equation it is assumed that scatterers are uniformly randomly distributed in the scattering volume, the pulse is assumed rectangular, the volume sizes are ($c\tau/2$, $\theta r/2$, $\theta r/2$), and the antenna is paraboloidal with the beam main lobe represented by a Gaussian function.

In terms of reflectivity expressed in mm^2/m^3

$$\eta = \frac{(4\pi)^3 16Ln(2) l^2 r^2}{c\tau\pi\theta^2 C_s} P_r \times 10^6 \quad [mm^2/m^3]$$

The reflectivity η is basically the resultant radar-cross section from all the scatterers in the illuminated volume. If we assume that the individual scatterers are spherical drops with sizes significantly smaller than the radar wavelength we can apply Rayleigh back-scattering approximation and relate η to the reflectivity factor, which, in this case, depends on the sixth moment of the water drop size distribution. When Rayleigh approximation does not apply the reflectivity factor Z is called equivalent reflectivity factor Z_e and represents an ensemble of spherical particles satisfying Rayleigh approximation. The relation between Z and η is given by:

$$Z_e = \frac{\lambda^4}{\pi^5 |K_w|^2} \eta$$, $[mm^6/m^3]$ and in logarithmic scale,10Log10(Z), is annotated as [dBZ].

$$K_w = \frac{m_w^2 - 1}{m_w^2 + 2}, \quad m_w = n'_w - jn''_w,$$

where m_w is the complex index of refraction. $|K_w|^2$ depends on the wave frequency and weakly depends on the temperature.

For pure water at 95 GHz and 0° C , m=2.84-j1.48; $|K_w|^2 = 0.711$ (R. Lhermitte, TGARS, v. 26, 1988, p.211). This is the value we use in our calibration. In case of pure ice, Lhermitte reports m=1.878-j0.000476; $|K_w|^2 = 0.209$ and thus for spherical ice particles the reflectivity factor, Z_i, must be adjusted by a factor of 3.413 (5.33dB):
$Z_i = 3.413 Z_e$

Ignoring the attenuation factor, the equivalent reflectivity can be expressed in dBZ as:

$$Z_{dB} = C_{dBZ} + 20Log10(r_{km}) + 10Log10(P_r),$$

where r_{km} is the distance to the target in kilometers , P_r backscatterd power from the target in milliwatts and C_{dBZ} is the calibration constant

$$C_{dBZ} = 10Log10(\frac{\lambda^4}{\pi^5 |K_w|^2}) + 10Log10(\frac{(4\pi)^3 16Ln(2)}{c\tau\pi\theta^2}) - C_{s\_dB} + 120,$$

where c=2.997925e08/m m/s, m=1.003 - refractive index for air, τ = 200e-9 s, θ = 0.0122 rad, λ=3.16 m, and $|K_w|^2$ = 0.711.

Substituting for all known quantities the calibration constant is given by

$$C_{dBZ} = 21.08 - 40Log10(R_{CRkm}) - 10Log10(P_{CR}).$$

4. Comments

We don't have accurate quantitative estimates of the bias in the $C_{dBZ@1km}$ due to the losses caused by the dual mirror setup and the protective rexolite windows in the radar antenna fairing as well as the approximations accepted in the radar equation. Our estimate of the uncertainty is not more than 3 dB.

Latest tests of the radar (June-July 1999) show the following uncertainties:

- ♣ Nonlinearities in both receivers: < ±0.5 dB
- ♣ Receivers' gain fluctuation (stable temperature) : < ±1.0 dB
- ♣ Error in the corner reflector orthogonality: < ±0.5 °
- ♣ Error in the corner reflector alignment with the radar antenna: varied by estimated < 5 °