Dual Antenna Configuration for MMCRs: A Method for Validating Antenna Characteristics at CART Sites

K. P. Moran, T. Ayers, and M. J. Post
National Oceanic and Atmospheric Administration
Environmental Technology Laboratory
Boulder, Colorado

Introduction

Atmospheric Radiation Measurement (ARM) Millimeter Wave Cloud Radars (MMCRs) rely on routine calibrations to provide accurate estimates of cloud reflectivities. Radar systems with scanning antennas routinely make use of calibrated corner reflectors to provide an external measurement of calibrated reflectivity (Sekelsky and McIntosh 1996). However, the MMCRs (Moran et al. 1998) are equipped with fixed beam vertically pointing antennas and must make use of an internal calibration. Instead of pointing the antenna at a calibrated target, the MMCR relies on combining measurements of the transmitted power, receiver gain, and antenna gain and beamwidth to compute an indirect measure of the calibrated reflectivity. Although the field calibrations of the transmitter and receiver are done frequently using reliable techniques, the antenna calibrations have been less definite. The antenna calibrations have only been performed at the time of manufacture at an antenna test range, and issues such as subsequent transportation stresses and weathering may have affected the antenna characteristics. Comparison with other well-calibrated radar systems at remote cloud and radiation testbed (CART) sites is often the only way to verify the performance of the MMCRs. The remoteness of these sites often limits the number of visiting instruments that can be used to compare with and calibrate the ARM instruments. It is useful then, to search for simple tools and procedures to assist with the calibration validation.

The National Oceanic and Atmospheric Administration/Environmental Technology Laboratory (NOAA/ETL) developed a dual antenna configuration for the MMCRs that can be easily transported to the field sites and installed on the radars. The system consists of a small 2-ft antenna with a known calibration, and a radio frequency (RF) switch with extra waveguide that installs on the antenna port of the radar. It is operated with special software used to collect data from the two antennas on alternating radar pulses, while observing clouds overhead. Knowing the RF path losses (waveguide, etc.) to the antennas and using the calibration of the 2-ft antenna, the characteristics of the site antenna can be verified by using the mean statistics of the cloud measurements. These results are compared with original antenna characteristics measured at the antenna test range, and will be used to help evaluate the antenna performance. This technique offers another useful tool for the ARM technical staff to assess the instruments' performance in the field and helps in maintaining accurate measurements.

Measured Power Difference

A comparison of the received power from the two antennas can be used to characterize the accuracy of their calibrations. The received power from the radar can be calculated using a standard form of the radar equation that applies to the MMCR: where **Z** is the reflectivity of the cloud region at range **R** with extent **ΔR**, $\mathbf{P_t}$ is the transmitted power, $\mathbf{G_o}$ is the antenna gain, ϕ and θ are the beamwidths, **K** is the index of refraction for water, $\mathbf{N_c}$ is the number of code bits used in pulse compression modes, $\boldsymbol{\lambda_r}$ is the wavelength, and $\mathbf{L_{sys}}$ are the system (waveguide) path losses:

$$P_r = \frac{Z\, P_t\, G_o{}^2 \theta\, \phi\, \Delta R\, \Pi^3\, 1K^2 1\, N_c 10^{18}}{512\, \ln 2\, R^2\, \lambda_r{}^2 L_{sys}} \tag{1}$$

For the dual antenna configuration the ratio of the received powers is dependent on the reflectivity, **Z**, of the scatterers in the two volumes, antenna gains $\mathbf{G_o}$, beamwidths ϕ and θ (radians) and path losses $\mathbf{L_{sys}}$. The log of the ratio is the difference of the received powers in dB, which can be obtained directly from the processed data. For a uniform cloud the reflectivity at a particular range would ideally be the same for both antennas. The natural variability of the reflectivity combined with the radar sampling volume sizes will result in a fluctuating difference signal. Statistics of the measured power difference are used to compare antenna characteristics (S and L refer to small and large antenna sizes).

$$\frac{P_{rS}}{P_{rL}} = \frac{Z_S}{Z_L} \frac{G_{oS}{}^2}{G_{oL}{}^2} \frac{\theta_S}{\theta_L} \frac{\phi_S}{\phi_L} \frac{L_{sysL}}{L_{sysS}} \tag{2}$$

The expected mean difference in the measured power between the two antennas can be computed from the original known characteristics of the antennas and the equipment configuration used.

Antenna Diameter	Far Field Gain	Beamwidth	Transmitter Path Loss	Receiver Path Loss
10 ft	57.2 dB	0.19 degrees	1.4 dB	1.6 dB
2 ft	44.5 dB	0.98 degrees	5.0 dB	5.4 dB

Expected power difference = 10 log [P_{rS}] - 10 log [P_{rL}] = -18.6 ± 0.4 dB

Far-Field Measurements

The specialized hardware for the dual antenna configuration uses a 2-ft portable antenna mounted on a manual positioner and RF switching electronics that selects the antenna for transmission and reception. The 2-ft antenna is placed near the perimeter of the large antenna (Figure 1) and pointed vertically. A long (5-ft) waveguide run connects the small antenna to the switching electronics (Figure 2). The configuration can easily be packaged, transported, and installed at existing CART sites.

Figure 1. 10-ft and 2-ft antennas at SGP.

Far-Field Measurements

During the spring 2000 cloud intensive operational period, the dual antenna configuration was used to compare the measured power difference between the 2-ft and 10-ft antennas. To avoid near-field effects the comparisons were limited to altitudes above 2 km. The cloud regions used for the study showed widespread variability in range and reflectivity and an editing mask was applied to reduce these effects (Figures 3 and 4). The editing removed the (1) near-field data, (2) data in receiver saturation with either antenna, (3) data near the noise level in either antenna, (4) data with large velocity differences, (5) data from regions of high reflectivity gradients near cloud boundaries and (6) data from regions with partially filled beam volumes.

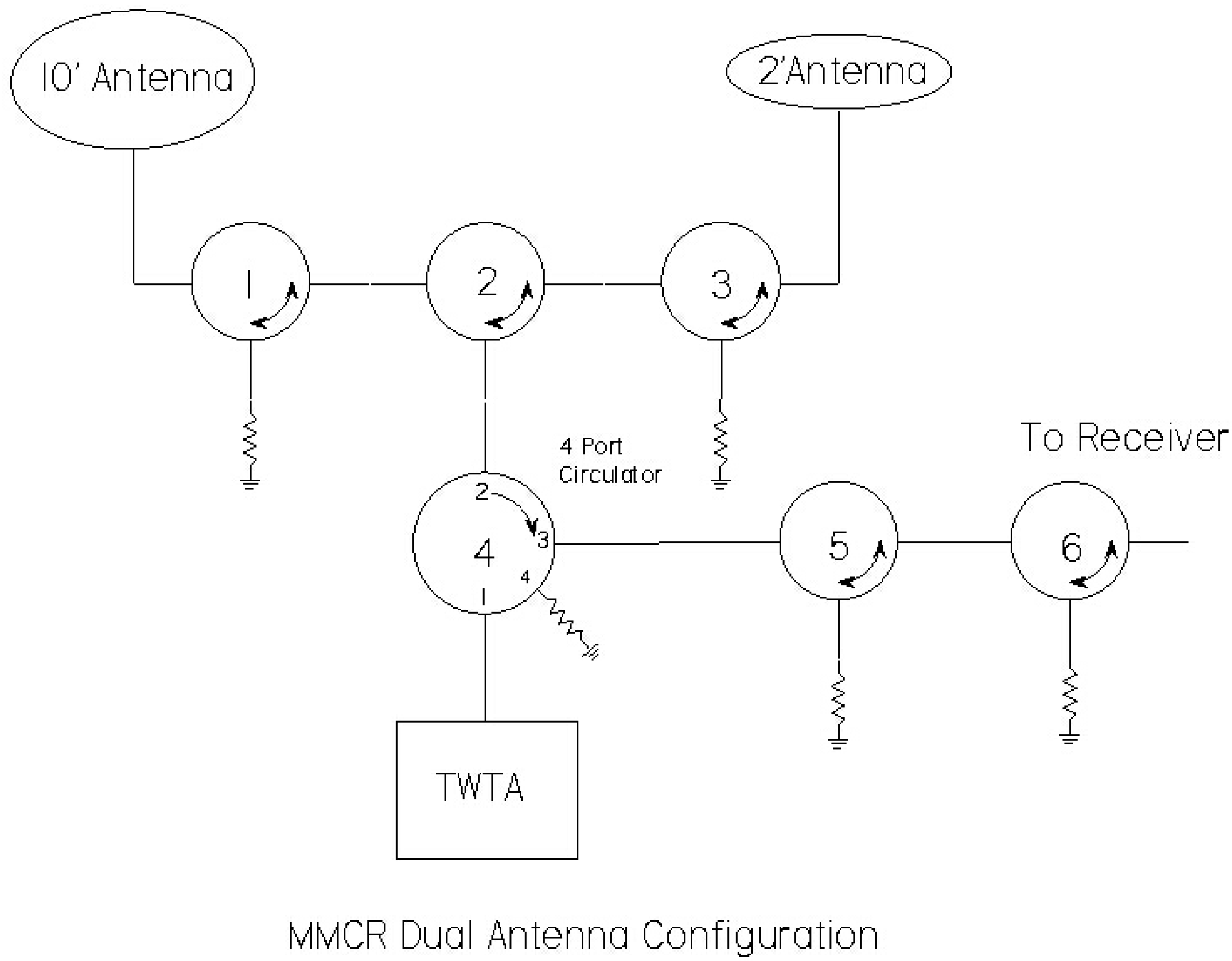

Figure 2. Radio frequency switch configuration.

The results of this comparison show a mean difference in the antenna measurements of -19.3 dB, which compares favorably with the -18.6 dB expected (Figure 5). The distribution has a standard deviation of 1.0 dB. The variability of the cloud that was used played a large role in determining the size of these uncertainties. A more uniform cloud layer would be better suited to this comparison because the scatter of differences would be reduced. Uncertainties in other measured quantities such as the RF path losses could contribute about 0.4 dB to the error.

Near-Field Measurements

The near-field regions of the two antennas are approximately 2 km for the 10-ft and 100m for the 2-ft antenna. Measured power differences between 100 to 2000 m are weighted by the near-field effects of the 10-ft dish. The MMCR is using a near-field correction formula that has not agreed with observation in past comparisons. A new formula (Sekelsky 2001, red curve) is plotted in Figure 6 along with the old

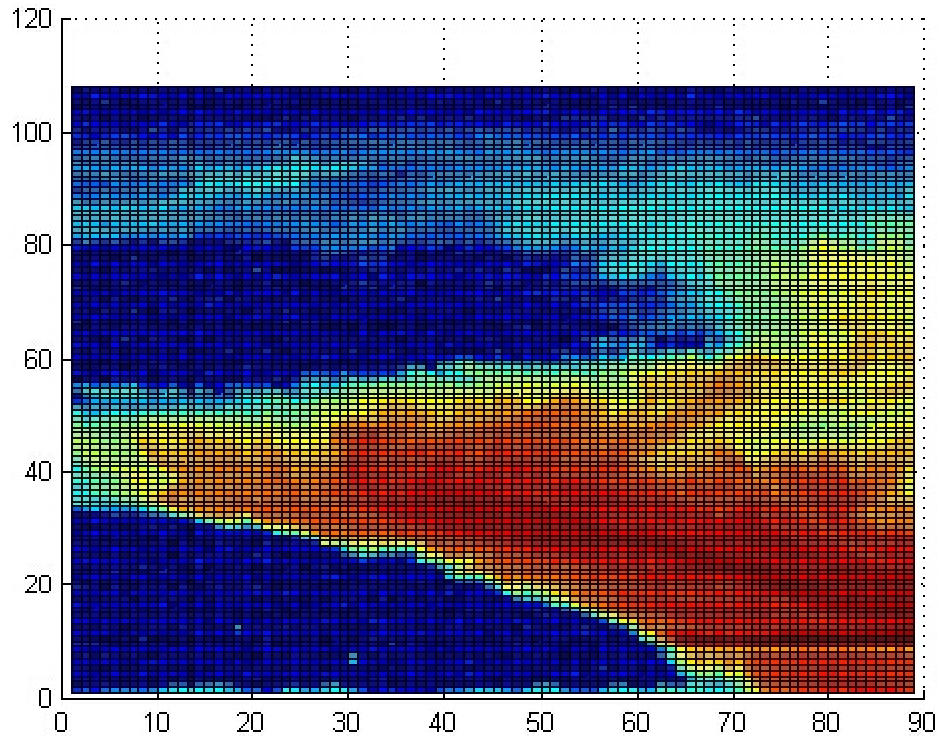

Figure 3. Cloud used in antenna comparison.

formula (Lataitis 1998, blue curve) and with measurements made with the dual antenna configuration (points). The plot shows good agreement of recent measurements with the new formula. The sample size is 200 points per range.

Conclusions

The first test of the dual antenna comparison technique demonstrated that a reasonable calibration verification can be achieved even using less than ideal clouds. The difference between the expected and measured values was 0.7 dB. The tests confirm the antenna has not undergone a significant degradation in expected performance and has maintained its original calibration well. Comparisons using more uniform clouds will provide more confidence about the accuracy of the technique.

Using data from the near-field region of the antennas has also led to a better understanding of the antennas' calibration. The dual antenna test results showed much better agreement with a new near-field correction formula of Sekelsky than with the equation used for the MMCR. This will lead to more accurate reflectivity estimates in the heights below 2 km in the MMCR data.

The dual antenna technique will provide ARM with another useful tool to aid in the verification of the MMCRs' reflectivity accuracy.

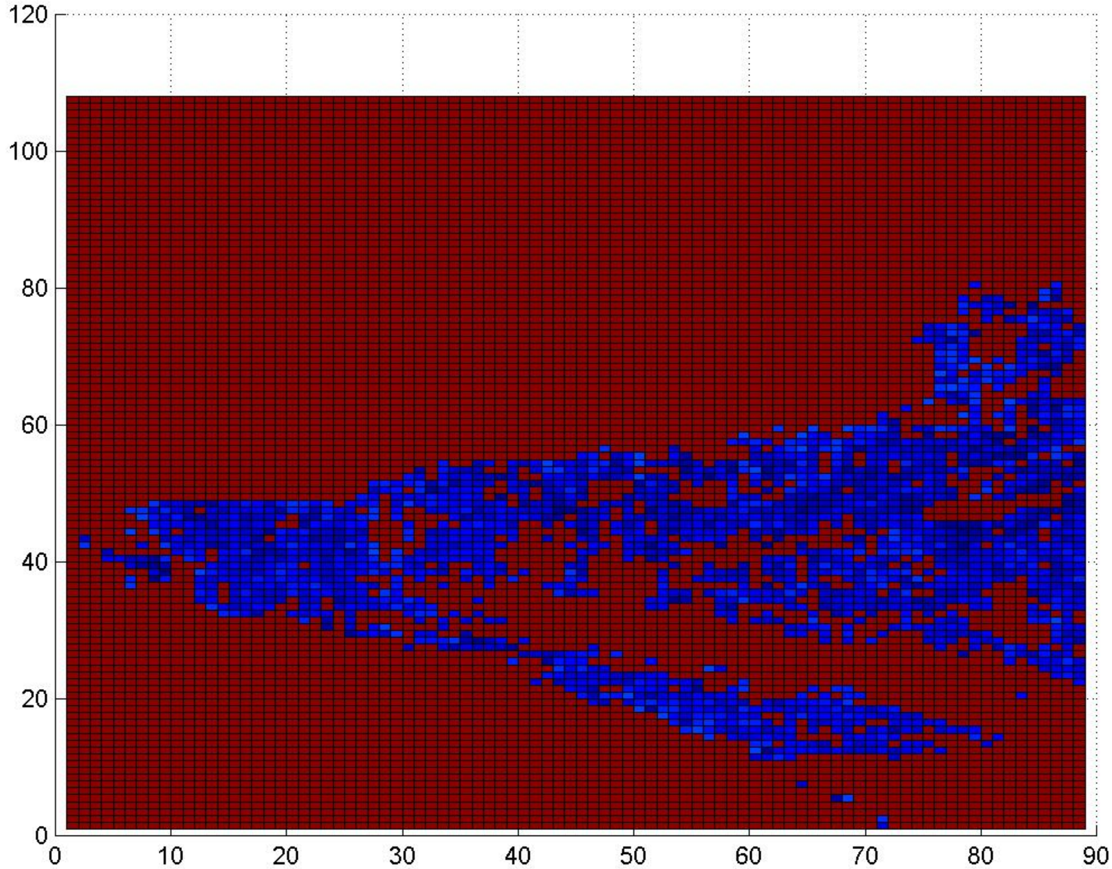

Figure 4. Mask applied to data.

Corresponding Author

K. P. Moran, ken.moran@noaa.gov, (303) 497-6575

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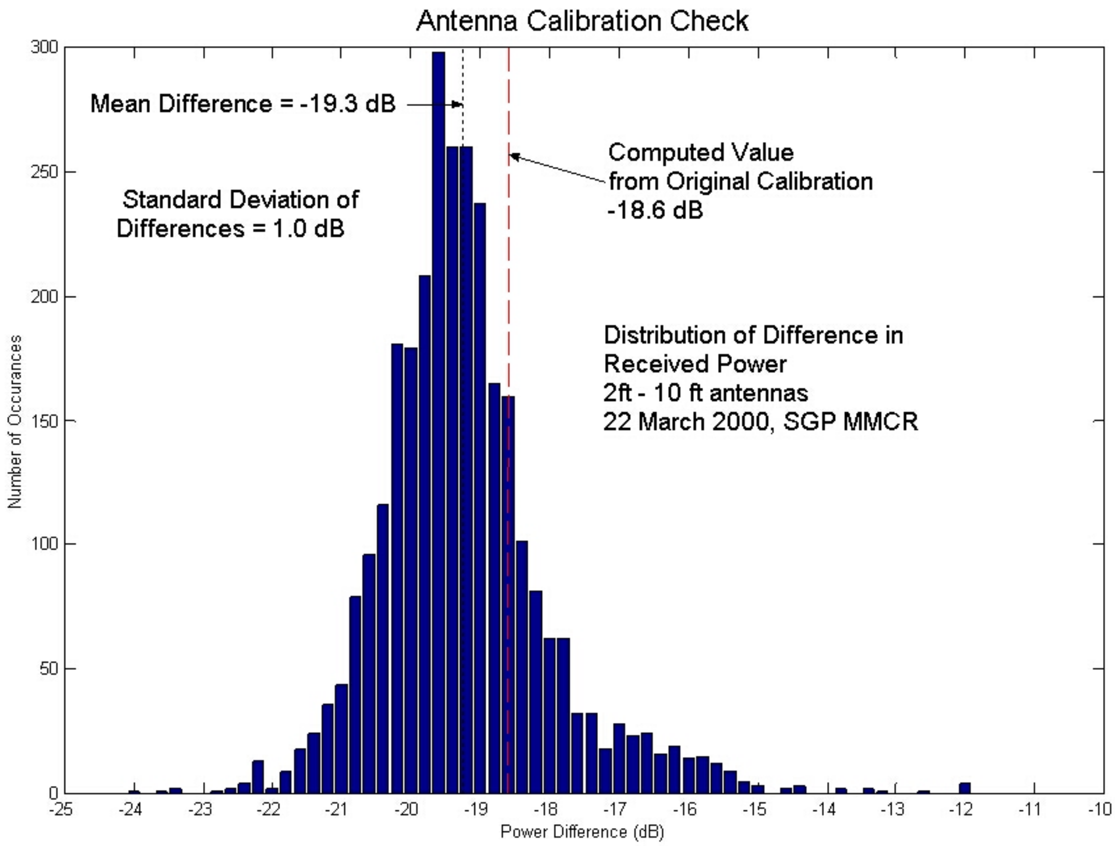

Figure 5. Distribution of antenna comparison.

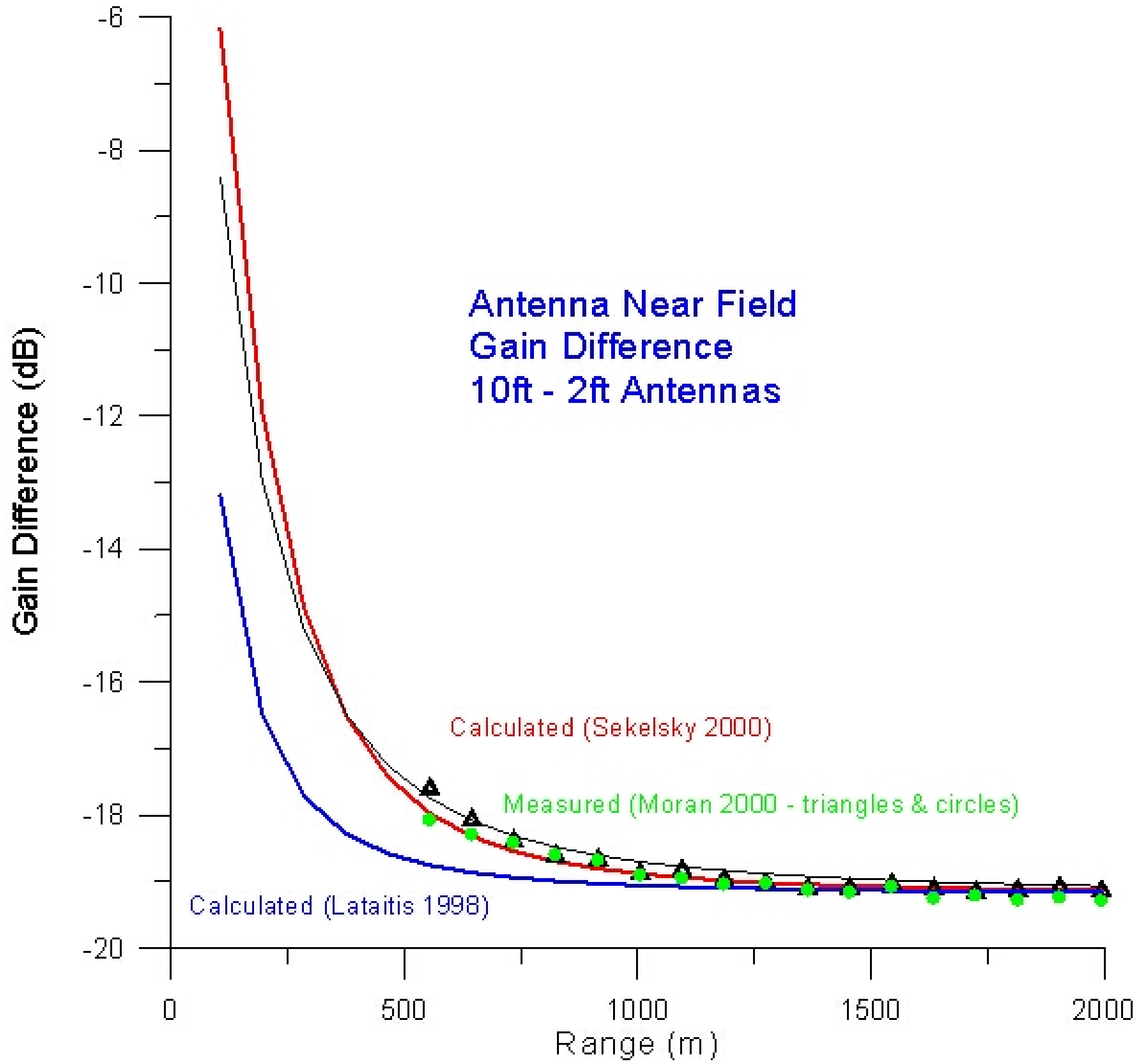

Figure 6. Near-field difference in 10 and 2 ft.