HIGH ACCURACY CROSS-POLARIZATION MEASUREMENTS USING A SINGLE REFLECTOR COMPACT RANGE

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Abstract

MI Technologies has developed a technique to achieve very high accuracy cross-polarization measurements using a single reflector compact range. The technique, known as the "Error Correction Code Algorithm" (ECCA) leverages the "ideal" performance of a single parabolic reflector when the feed axis is aligned to the parabola axis. ECCA mathematically corrects for the amplitude taper induced by the feed axis alignment.

Historically, 'conventional' compact range polarization purity has been limited to »-30 dBi. The ECCA technique, however, lowers the cross-polarization error to »-48 dBi. This performance has been verified in two separate inter-range measurement comparisons with the National Institute of Standards and Technology. The results of these tests prove ECCA is an extremely accurate technique for low cross-polarization measurements and provides a lower cost, superior performance alternative to dual-reflector systems when low cross-polarization measurements are required.

Keywords: Geometric-Optics, Compact Range, Cross-Polarization, Planar Near Field.

1.0 Introduction

Accurate measurement of an antenna requires recording of the antenna response to an incident wave that has uniform amplitude, phase and polarization in a plane normal to the direction of propagation. Any deviation from the incident field requirement introduces error into the antenna measurement. It is the job of any antenna range to produce an incident field that approximates this requirement. In a single reflector compact range it is not possible to optimize all three parameters. Polarization purity is usually traded for field illumination.

In the past, low cross polarization measurements have typically required dual-reflector systems which provide the flexibility to achieve both amplitude uniformity and polarization purity as long as the Mitzugutch condition is maintained. However, dual reflector systems come with their own set of cost and performance penalties, including higher cost (approximately 2x), higher edge scattering, higher direct feed radiation, and increased sensitivity to mechanical tolerance. These factors combined limit the sidelobe measurement accuracy and the achievable cross-polarization to -38 to -45 dBi. The technique described herein allows for measurement using a single reflector compact range while achieving polarization purity equal to or exceeding that of a dual reflector system.

2.0 The Relation of Amplitude Taper and Cross-Polarization in an Offset Reflector

It is well known that if one defines the polarization reference vectors by Ludwig's[1] third definition, then it can be shown that an offset fed single reflector introduces no cross-polarized field components[2] as long as the axis of the feed is coincident with the axis of the parabolic reflector. Therefore, cross-polarization content is purely a function of the feed performance and orientation of the feed with respect to the compact range reflector.

Typically, the feed in a single reflector compact range is tilted upwards in order to achieve a test zone field with symmetric amplitude across the quiet-zone aperture. The rotation of the feed coordinate system with respect to the reflector coordinate system causes the co-polarized component of the feed to couple into the cross-polarized component defined by the reflector coordinate system, as shown by Chu[3]

Therefore, one can achieve low cross-polarization in the incident field by aligning the compact range feed to the axis of the reflector. This feed orientation will produce a taper across the aperture of the quiet-zone and perturb the antenna co-polarized response. However, the induced field taper can be easily calculated by geometrical optics and its effect removed from the measured antenna pattern.

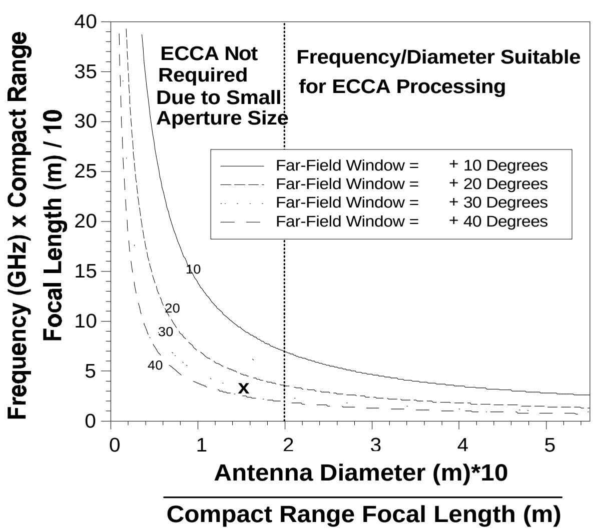
MI Technologies has developed the ECCA measurement technique to correct the aperture field taper on a compact range with the feed aligned to the parabolic axis, thereby eliminating the geometry induced cross-polarization present in conventional compact range measurements. Numerical simulation and actual inter-range measurement comparisons to near-field measurements conducted by NIST have confirmed the accuracy of this technique.

3.0 The ECCA Technique

In an earlier work[4] it was demonstrated that the ECCA technique was effective for low cross-polarization measurements when compared to NIST spherical near-field measurements. The cross-polarization levels in the compact range matched the NIST measurements to within an error level of < -40 dB. (Note: This work also showed that the cross-polarization error level is < -40 dB for antennas with apertures less than two-tenths of the compact range reflector focal length. See Figure 1.)

The ECCA technique is based upon the Fourier transform relation between the far-field and the aperture field of an antenna and Richmond's generalized reaction theorem. The process requires measurements to be made over a solid angle region of the antenna pattern by measuring the antenna at a raster of azimuth and elevation points. This measurement must be made for two orthogonal polarization components, with the compact range configured in the "alternate" configuration of Figure 2.

Figure 1. ECCA Processing Criteria



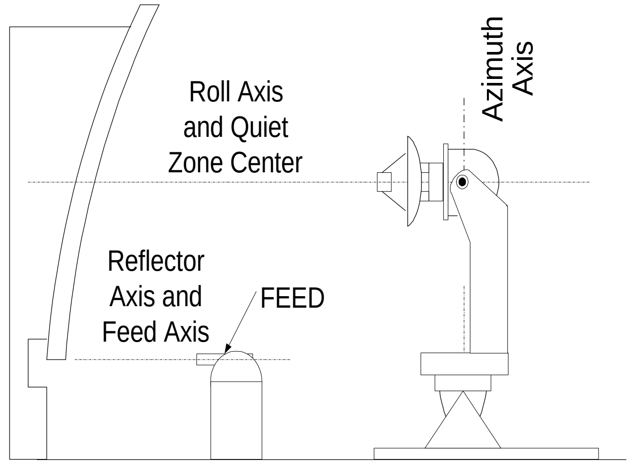


Figure 2. The Alternate Configuration

The ECCA process transforms the measured far-field to the equivalent aperture plane fields which is the complex product of the true antenna aperture field and the incident field produced by the compact range.

If the gain pattern of the feed and the reflector geometry are known, the incident field can be calculated by geometric optics. Once the incident field is computed, it can be removed from the aperture plane field to yield the "corrected" aperture plane field. The "corrected" aperture plane field can be transformed back to the far-field to produce the "corrected" far-field pattern for both the co-polarized and cross-polarized antenna patterns.

The ECCA processing software is provided as an optional module to the MI Technologies MI-3000 antenna measurement software. The software allows the user to estimate the expected cross-polarization level of the measurement and to decide whether to use the ECCA measurement technique. If ECCA is used, the software will collect and mathematically process the measurement data and calculate the corrected cross-polarized

4.0 ECCA Algorithm Verification

The ECCA algorithm was first tested using numerical simulation of an antenna in a Compact Range quiet-zone field. Numerical simulation showed exceptional results. Based on the excellent numerical results, a comparison study was conducted using measurement comparison techniques of the co- and cross-polarized fields of a 2-foot diameter ‘golden antenna’. The antenna was measured in a MI Technologies 5704 compact range at 13 GHz. Note; the 5704 has a focal length of 12 feet. Therefore, the antenna diameter to compact range focal length is approximately 0.17 which falls on the left side of the vertical line in Figure 1 indicating that ECCA processing is not required to achieve low cross-polarization error.

Measurements were also made on a MI Technologies spherical near-field (SNF) system. The error in the cross-polarization of the ECCA processed measurement compared to SNF is on the order of -40 to -45 dBi. This level is well within the requirements for most any antenna application. These results also confirm that a compact range in the conventional configuration has excellent cross-polarization error when the AUT dimensions are small compared to the reflector focal length. (The reader is urged to refer to reference [4] for further detail of this experiment.)

5.0 Planar Near-Field Measurement Comparison

As a follow up study, a six-foot "golden" antenna was measured on a MI Technologies 5708 Compact Range. The antenna was also measured by the National Institute of Standards and Technology (NIST) which served as the reference for the correct antenna pattern. The antenna diameter to compact range focal length is approximately 0.25. Figure 1 indicates that the cross-polarization level may be above acceptable tolerances and ECCA processing should be applied.

The co-polarized measurements using the 'conventional' configuration of the compact range show excellent global agreement with the NIST PNF co-polarized measurements. The contour plot of the NIST co-polarized measurement is shown in Figure 3 and the co-polarized measurement with the compact range in the standard configuration is shown in Figure 4.

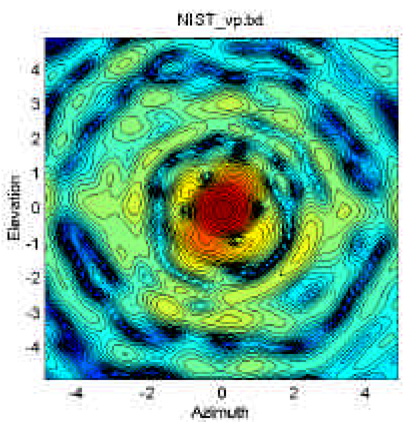


Figure 3. Co-Polarized NIST Measurement

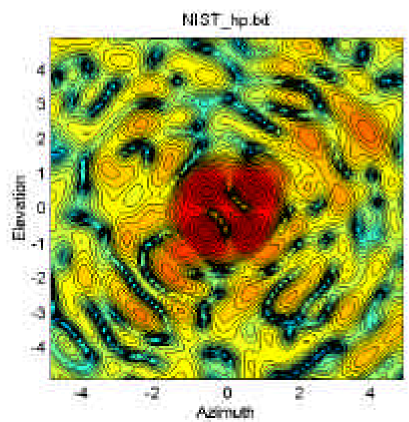


Figure 5. Cross-Polarized NIST Measurement

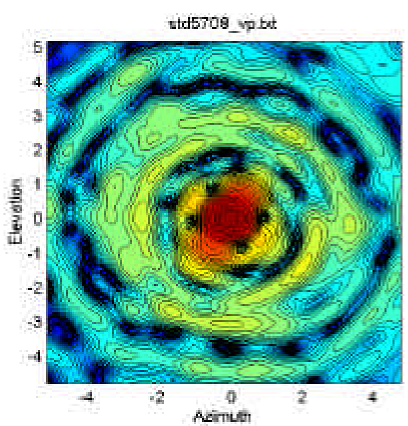


Figure 4. Co-Polarized Standard Measurement

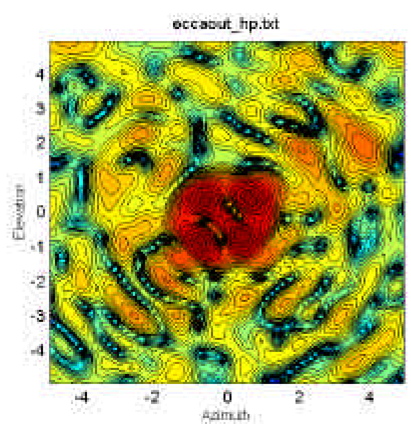


Figure 6. ECCA Cross-Polarized Measurement

The cross-polarization compact range measurement made in the 'alternate' configuration is in excellent agreement with the NIST cross-polarized measurements and the cross-polarization accuracy is further enhanced after processing the data with the ECCA algorithm. The contour plots of the cross-polarized measurements are shown in Figure 6.

The results of these tests confirm the operation of the ECCA process. The equivalent error between the inter-cardinal cross-polarization peaks is shown in Table 1. The four columns of this table show the measured value of the four inter-cardinal plane cross-polarization peaks. The first row shows the values measured by the NIST planar near-field measurement, which served as the standard of comparison. The second row shows the values measured by a "conventional" compact range measurement. The third and forth rows show the equivalent measurement error and the average measurement error.

The fifth row is a repeat of the first row, and the sixth row is the value of the cross-polarized peaks measured by the ECCA process.

Rows 9 and 10 show the NIST measurement and the ECCA processed measurement of the cross-polarized pattern. Rows 11 and 12 show the error and the average measurement error between the NIST PNF measurement and the MI Technologies ECCA measurement.

The comparison of each data set with the NIST data shows conclusively that a significant improvement in cross-polarization measurement accuracy is realized with the ECCA technique when compared to standard compact range measurements.

Table 1. Comparison of Intercardinal Cross-Polarization Peaks for Standard, Alternate, and ECCA Processed Measurements

Measurement Type	Cross-Pol Peak Number			
	1	2	3	4
NIST PNF	-22.6	-23.2	-22.0	-22.8
Standard Cfg.	-26.7	-26.7	-27.9	-28.0
Equivalent Error*	-31.2	-32.8	-28.1	-29.7
Average	**-29.7**			
NIST PNF	-22.6	-23.2	-22.0	-22.8
Alternate Cfg.	-23.0	-23.0	-23.1	-22.6
Equivalent Error*	-49.6	-57.3	-40.4	-55.0
Average	**-47.9**			
NIST PNF	-22.6	-23.2	-22.0	-22.8
ECCA	-23.1	-23.1	-22.8	-22.4
Equivalent Error*	-48.8	-60.3	-43.0	-49.1
Average	**-48.82**			

**Equivalent Error or Equivalent Extraneous Signal Level Error is collection of all possible errors in the measurement including field-purity, instrumentation and technique.*

6.0 Summary

The ECCA process has been developed mathematically by Cook, et al.[4] The process has been verified by numerical simulation, and in two separate inter-range antenna measurement comparisons. The results clearly reveal that it is possible to make cross-polarization measurements using a single reflector compact range that exhibit very low (<-40 to -45 dBi) equivalent extraneous signal level error*. The verification of this technique eliminates the need for expensive dual-reflector systems when making these types of measurements and advances the art of accurate low-cross polarization measurements.

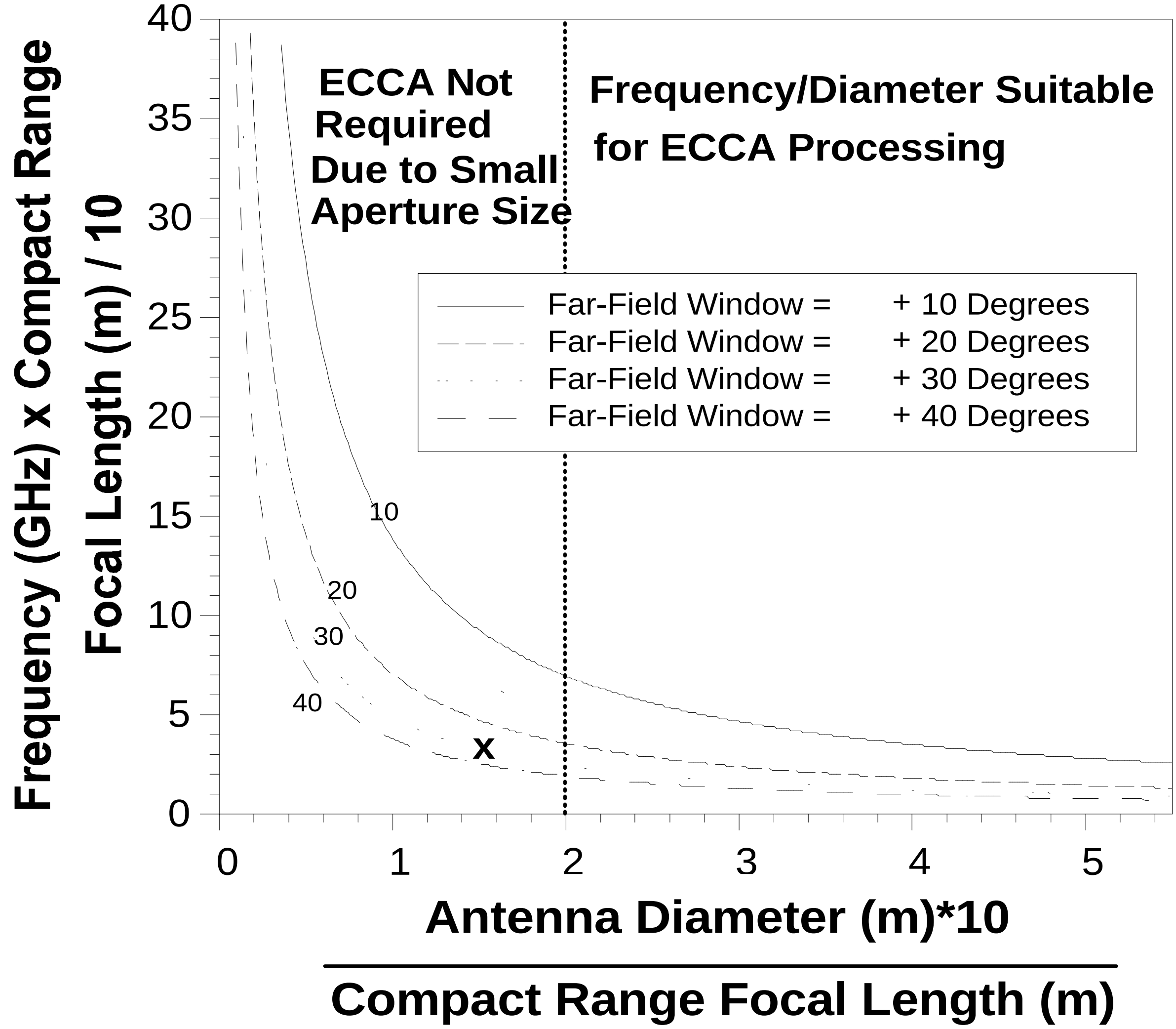
Currently an investigation is underway to examine a modified version of the ECCA technique that does not require a solid-angle of data to be measured. We have also introduced the Model 5720 dual-reflector system for conventional low-cross polarization measurements. We have designed a series of extremely low cross-polarization feeds that exhibit 60 dB axial ratio on boresight. Given these advances, MI Technologies is well suited to provide a custom solution to the low cross po-

References:

1. A. C. Ludwig. "The Definition of Cross Polarization," IEEE Trans. Antennas and Propagat., vol. AP-2, pp., 116-119, Jan. 1973
2. Johannes Jacobson, "On the Cross Polarization of Asymmetric Reflector Antennas for Satellite Applications", IEEE Trans. Antennas and Propagat., March 1977, pg. 276
3. T. S. Chu, "Cancellation of Polarization Rotation in an Offset Paraboloid by a Polarization Grid", The Bell System Technical Journal, vol. 56, No. 6, July-August 1977
4. David C. Cook, James H. Cook, Jr., Rebecca Kaffezakis, "Cross-Polarization measurement Accuracy Improvement on a Single Reflector Compact Range", AMTA 1996 Proceedings, pg. 394.

Appendix

Full Size Illustrations



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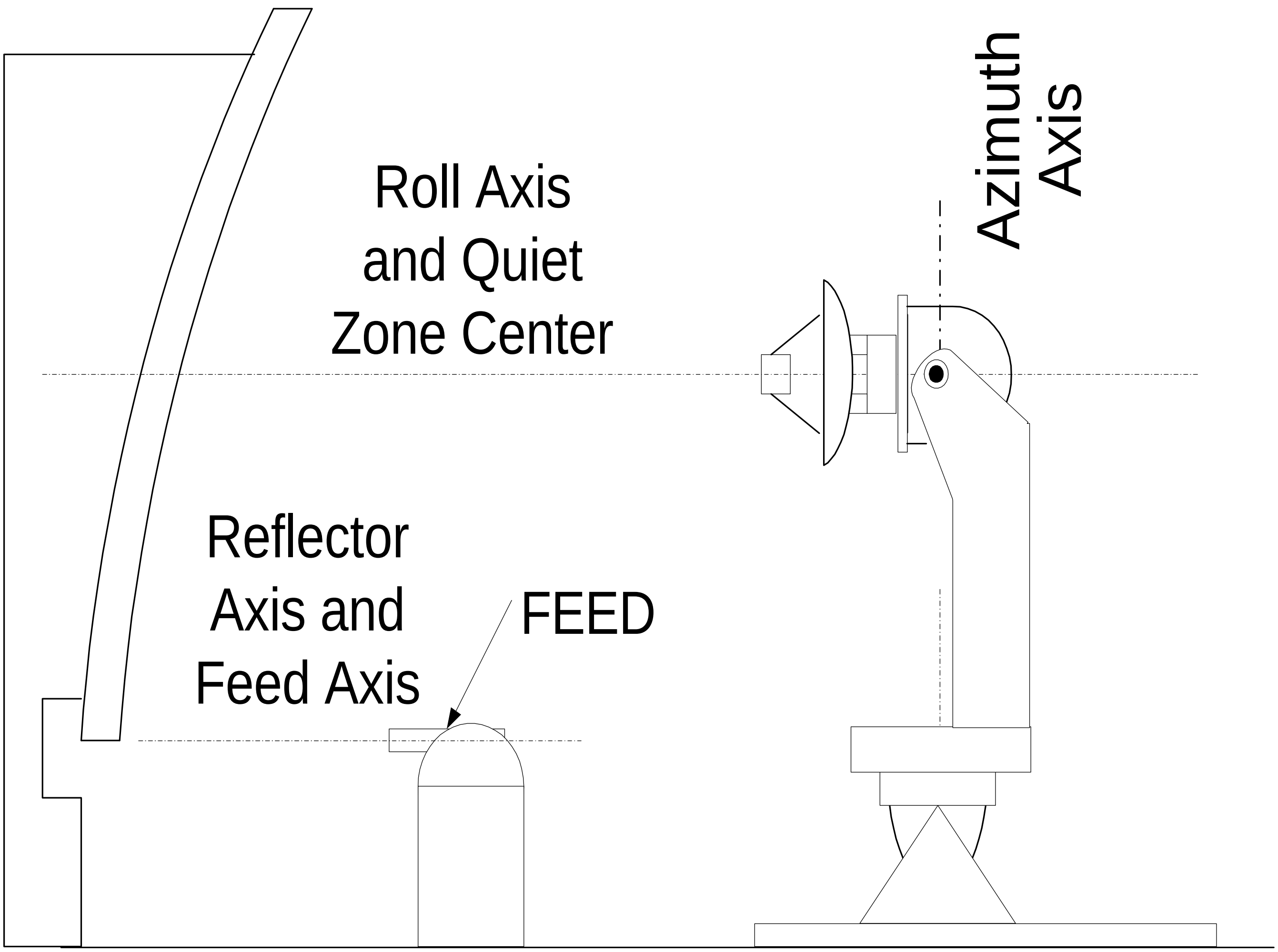
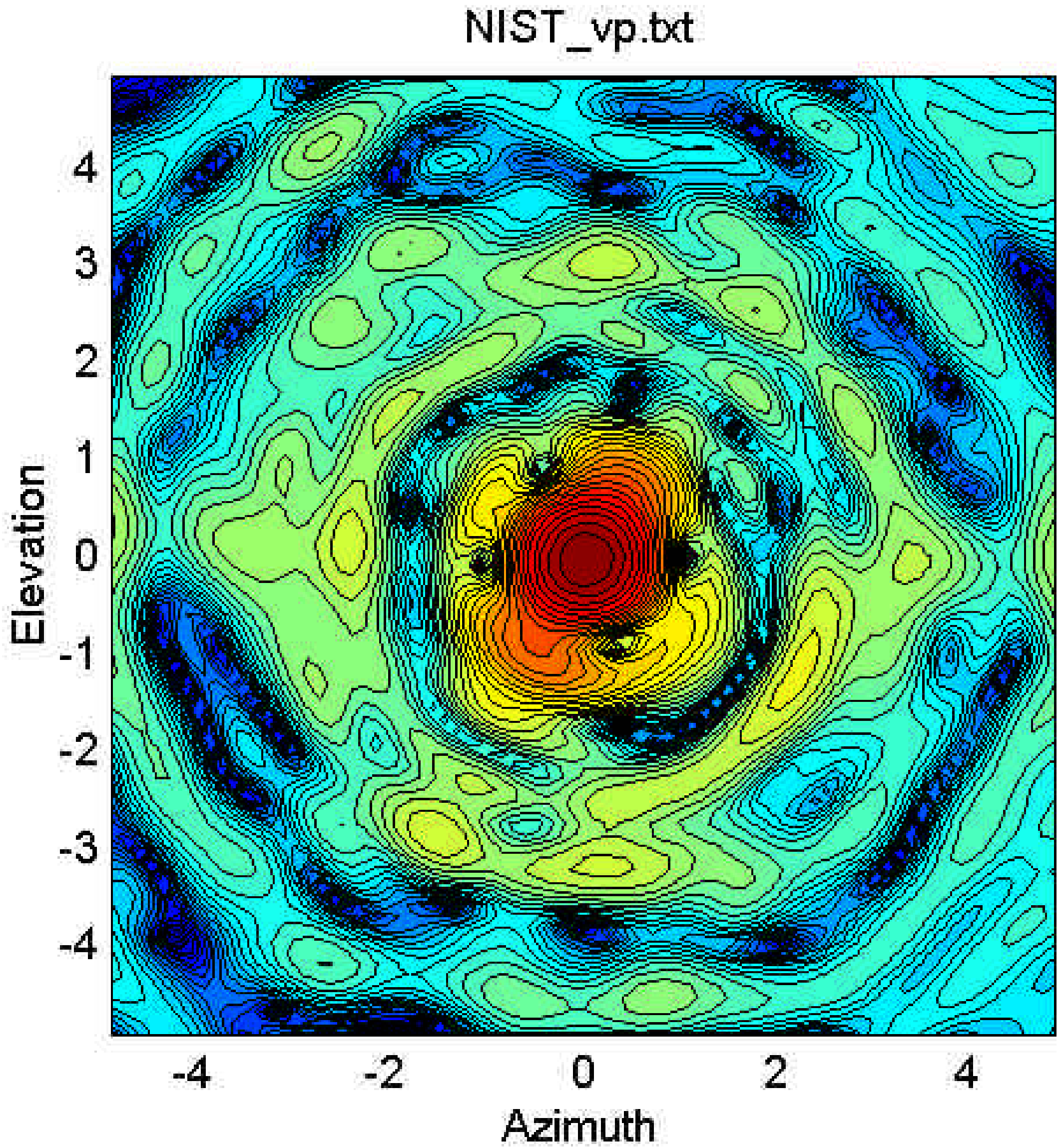


Figure 2. The Alternate Configuration



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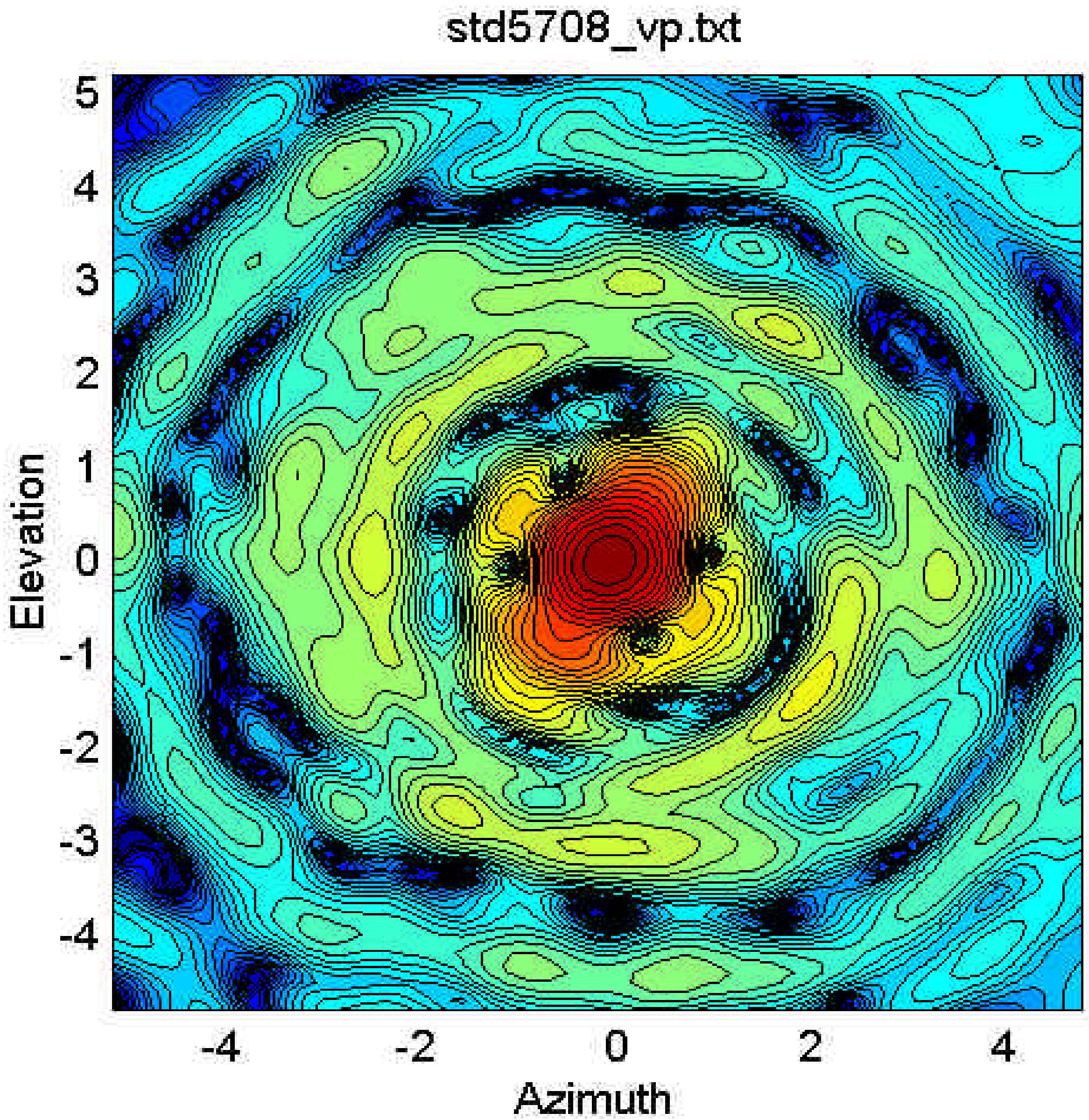

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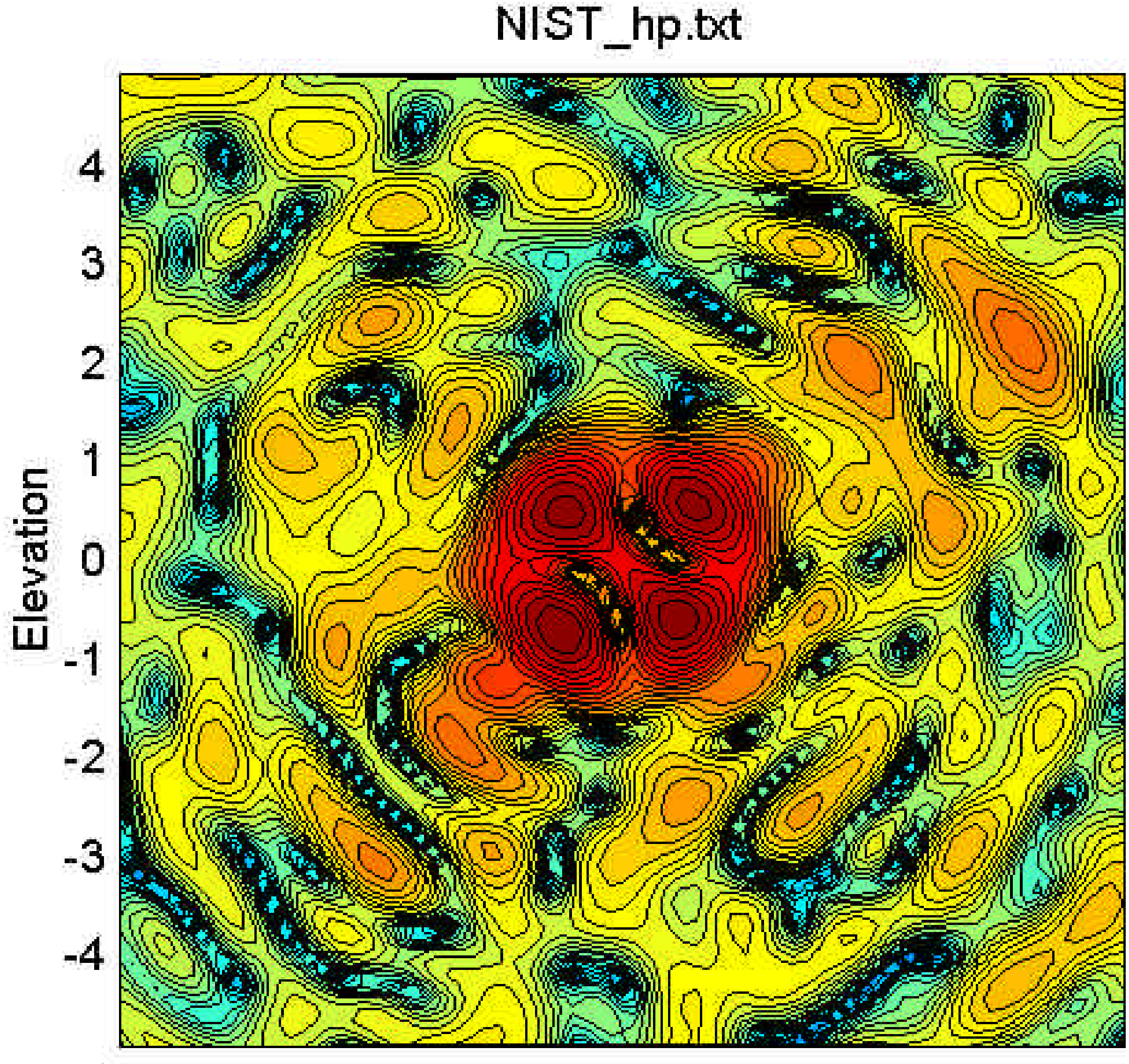
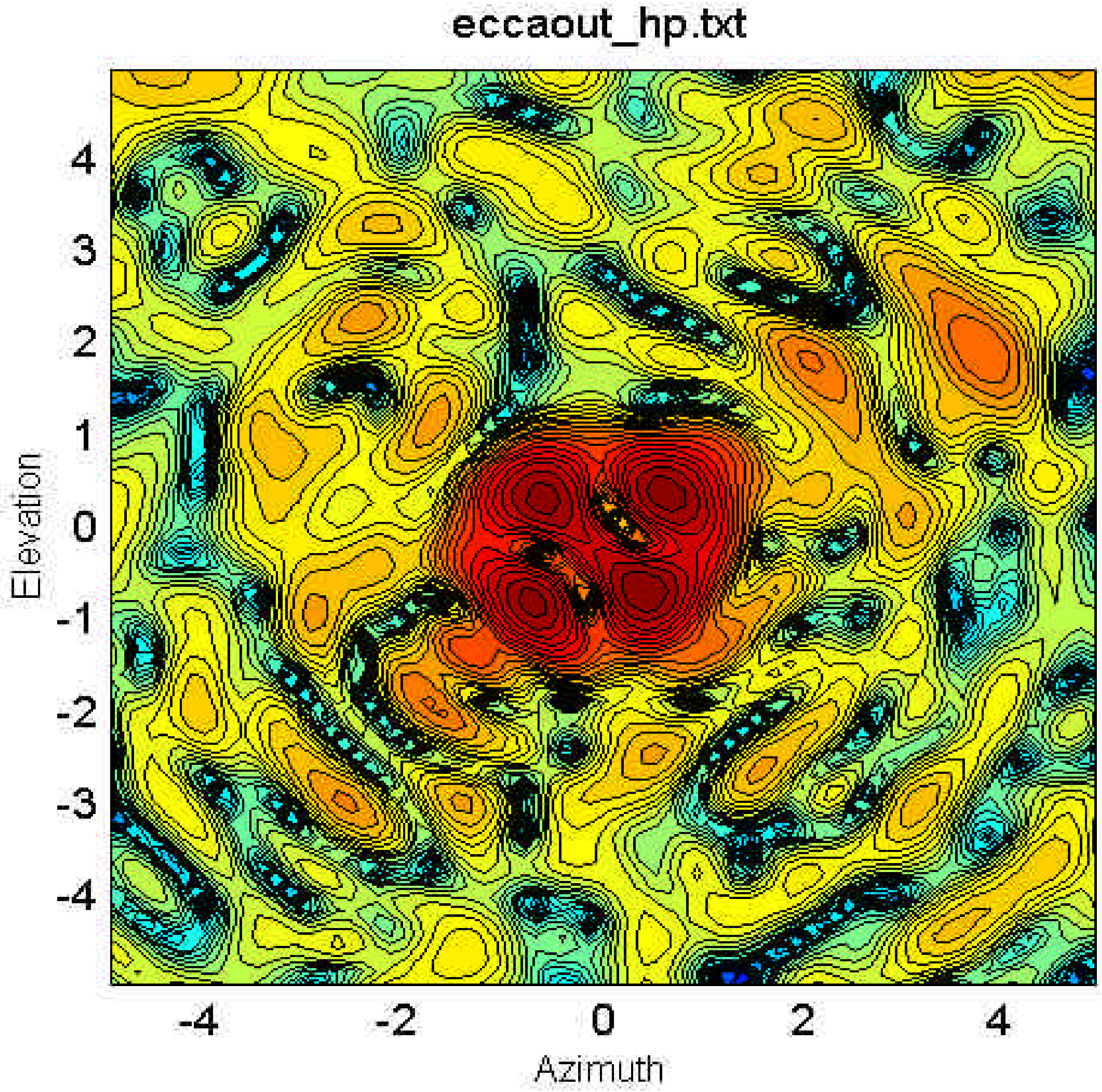


Figure 5. Cross-Polarized NIST Measurement



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