THE ALIGNMENT OF A SPHERICAL NEAR-FIELD ROTATOR USING ELECTRICAL MEASUREMENTS

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ABSTRACT

The mechanical rotator must be correctly aligned and the probe placed in the proper location when performing spherical near-field measurements. This alignment is usually accomplished using optical instruments such as theodolites and autocollimators and ideally should be done with the antenna under test mounted on the rotator. In some cases it may be impractical to place the alignment mirrors on the AUT or optical instruments may not be available. In these and other cases, it is desirable to check alignment with electrical measurements on the actual AUT and probe. Such tests have recently been developed and verified. Appropriate comparison and analysis of two near-field measurements that should be identical or have a known difference yields precise measures of some rotator and probe alignment errors. While these tests are independent of the AUT pattern, judicious choice or placement of the antenna can increase the sensitivity of the test. Typical measurements will be presented using analysis recently included in NSI software.

Keywords: Antenna Measurements, Near-Field, Measurement Diagnostics, Range Calibration, Errors.

1. INTRODUCTION

The spherical near-field theory requires that data on the Antenna Under Test (AUT) be obtained at equally spaced points in θ and φ on the surface of a sphere that completely encloses the AUT. Conceptually this is accomplished by defining a sphere that is fixed to the AUT and moving the probe over the surface of this sphere. Amplitude and phase data are then obtained at equally spaced points on the sphere. Since it is difficult to construct a mechanical device that will move the probe and leave the antenna fixed, the scanning is usually accomplished by leaving the probe fixed and rotating the antenna and its hypothetical sphere with a two-axis rotators. If the rotator is properly aligned, the probe will describe lines of constant θ or φ on the sphere and correct data will be obtained. If the rotator is not correctly aligned, the radial distance will change as the AUT is rotated, and the measurement points will not be at equally spaced intervals in θ or φ. The resulting data will not produce correct results when processed through the spherical programs.

In most cases, the spherical rotator is aligned using a combination of mechanical and optical devices before the AUT is mounted for measurements. It is assumed the rotator remains aligned when the antenna is attached and measurements are performed. It would be very desirable to have electrical measurements, i.e. those derived from the measured amplitude and phase data, which would verify the alignment of the rotators with the actual AUT in place. Such measurements could also be used in place of the mechanical/optical procedures when appropriate, and could also be used periodically during a measurement sequence to ensure continued alignment. This paper describes such electrical measurements that have recently been developed and tested at Nearfield Systems Inc. (NSI).

2. DEFINITION OF SPHERICAL ALIGNMENT ERRORS

The various alignment errors that will be considered are shown in Figs 1 and 2, which are views in the yz and xz planes of the measurement sphere. These are:

1- Non-orthogonality of the θ and φ axes;
2- Y-zero error;
3- θ-zero error;
4- X-zero error;
5- Non intersection of the θ and φ axes;
6- Probe axis not parallel to the z-axis.

Each of these will be described along with the methods used to detect misalignment and make corrections.

2.1 Non-Orthogonality of θ and φ Axes.

The θ-axis is defined by the axis of rotation of the lower of two rotators, and is usually aligned to be vertical.

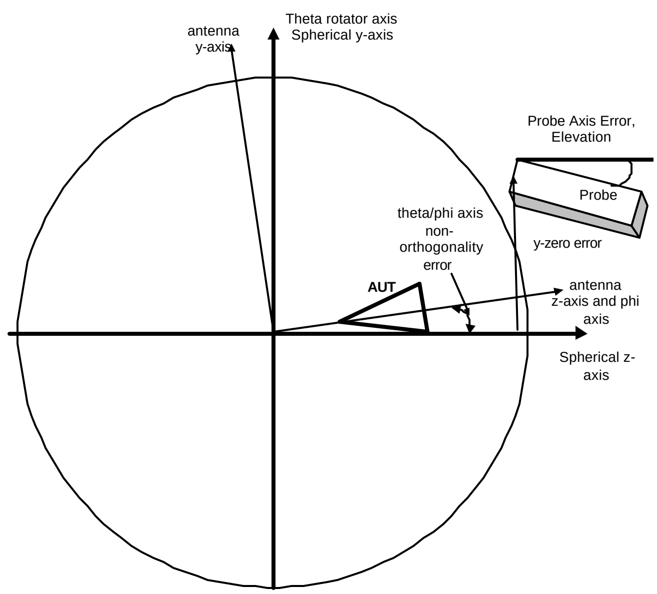

Figure 1 Y-Z Plane of Spherical Coordinate System.

This alignment can be accomplished very easily by placing a precision level on the rotator and placing shims under one end to make it level. The θ rotator is then rotated 180 degrees and in general the level will not remain leveled. The supports under the rotator are then adjusted to correct half of the change, and the shims are adjusted to correct the remaining change. This 180 degree rotation and adjustment are repeated for 0/180 as well as 90/270 positions until the level remains unchanged for all rotation angles. The θ-axis is then vertical. A similar technique can be used to align the φ-axis to be horizontal. An adjustable mirror is temporarily placed on the φ-rotator with the normal to the mirror approximately along the φ-axis. Using an optical autocollimator, and rotating the mirror with the φ-rotator, the mirror is adjusted until the normal to the mirror and the φ-axis are coincident as indicated by collimation remaining constant with φ-rotation. The supports on the tower of the φ-axis are then adjusted until the mirror axis is horizontal. If an autocollimator is not available, the alignment can be accomplished by one of two other methods. One makes use of a precision level and a flat "probe" placed temporarily on the φ-rotator. The other uses a flat mirror, low-cost laser and water level. These techniques will be described in more detail elsewhere.

When these alignments are completed, the AUT is placed on the φ-axis rotator and electrical tests can begin. Currently, the electrical tests are not sensitive enough to distinguish between non-orthogonality and y-zero errors. It is necessary to rely on the optical or level alignment to initially set the orthogonality.

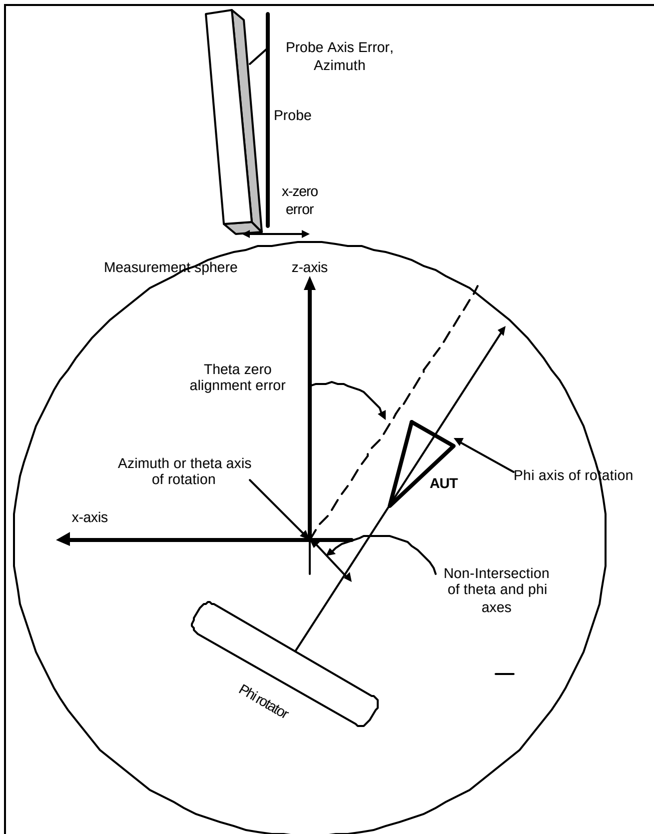

Figure 2 X-Z Plane of Spherical Coordinate System.

2.2 q-ZERO AND X-ZERO TESTS AND ALIGNMENT

The measurements to detect these errors, and most of the other alignment errors consist of two θ-scans taken at φ = 0 and φ = 180. The 180-scan is then inverted and compared with the 0-scan by calculating the difference in amplitude and phase between the two scans as shown in Figs. 3 and 4 for a 15 dB gain horn at 10.0 GHz. The amplitude difference and part of the phase difference are due to the combined x-zero and θ-zero errors. This is because the antenna is fixed to the φ-axis, the pattern is rotated about the φ-axis for the 180-scan, and the position of the probe relative to the antenna is changed. This is apparent in the offset between the patterns in Figs. 3 and 4.

The amplitude difference is given by,

$$\Delta a = a_{180} - a_0 = \frac{da}{dq}\left(\Delta q - \arcsin\left(\frac{\Delta x}{R}\right)\right), \qquad (1)$$

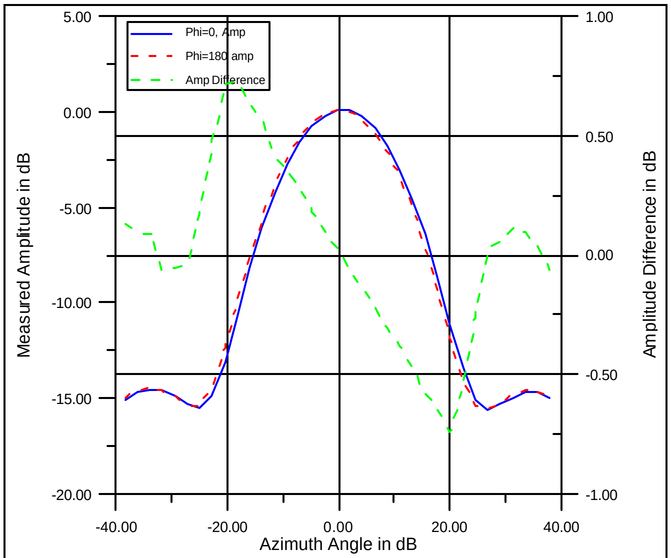

Figure 3 Measured Amplitude and Amplitude Difference Showing Effect of q-zero and X-zero Alignment Errors.

where a is the measured amplitude, R the radius of the measurement sphere, Δx and Δq the alignment errors, and $\frac{da}{dq}$ the slope of the amplitude curve. The error can be calculated from a knowledge of the slope and the difference shown in Fig. 3, however since both curves are in dB, it is easier to guess at the error, make a change in the θ-zero setting and then repeat the test. It is know that a negative slope in the amplitude difference curve implies that the θ-zero error is also negative, and the φ-axis must be moved in the positive direction. The θ-zero was changed by 0.30 deg. to make the amplitude flat for the data shown in Fig. 3. This adjustment is generally made first since it is the easiest to make, and it leaves only the non-intersection error to produce a difference in the phase curve.

2.3 NON-INTERSECTION OF q AND j AXES

The phase curve obtained after making the above adjustment is shown in Fig. 5 and shows that the maximum phase error has been reduced to about 15 deg. as compared to 30 deg. before the adjustment was made. The remaining
phase difference is due to the non-intersection of the θ and φ axes, and the difference curve is given by,

$$\Delta y = y_{180} - y_0 = \frac{-720\sin(q)\Delta L}{l}, \qquad (2)$$

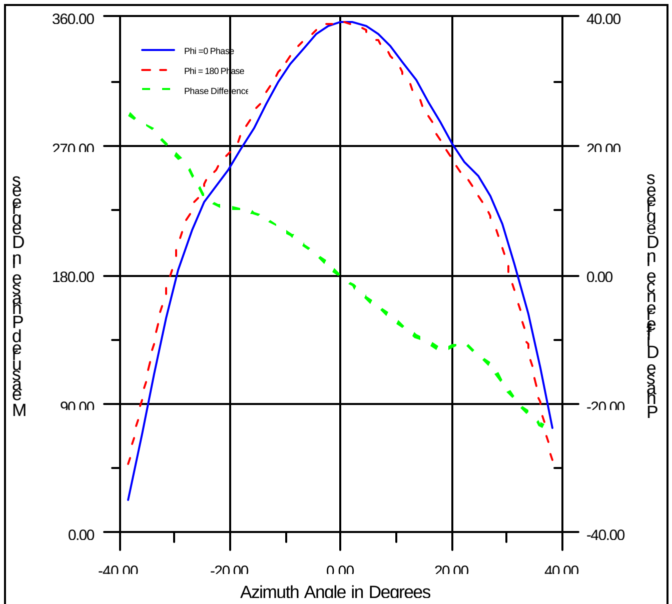

Figure 4 Measured Phase and Phase Difference Showing Effect of q-Zero and X-Zero and Non-Intersection Alignment Errors.

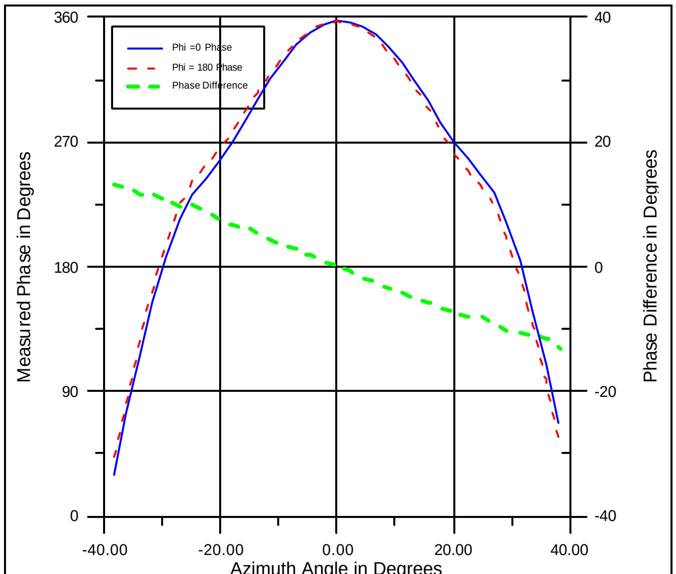

Figure 5 Measured Phase and Phase Difference Showing Effect of Non-Intersection Error Only.

where Δy is the phase difference, ΔL the non-intersection error, and l the wavelength.

For the receivers that use the time convention of e^{jwt}, the phase will decrease with increasing distance between the AUT and the probe. For this time convention and the phase difference as defined in Eq. (2), an offset error in the +x direction as shown in Fig. 2 produces a negative phase difference slope which explains the negative sign in (2).

From Fig. 5 and Eq. 2, the non-intersection error is 0.097 cm. The φ-axis can be moved with a translation stage, or by placing shims between the φ rotator and its mounts. When this is done the resulting amplitude and phase difference curves are shown in Fig. 6.

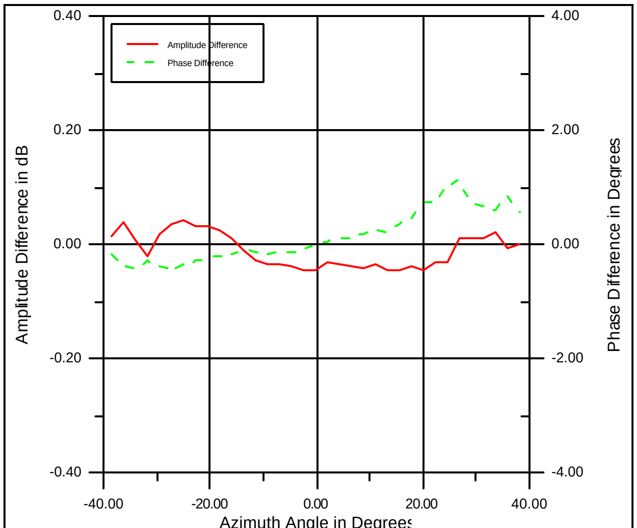

Figure 6 Amplitude and Phase Difference After q-Zero and Non-Intersection Alignment.

Additional adjustments could be made to improve the alignment, but from Fig. 6 it is apparent that the θ-zero error is less than 0.04 deg. and the non-intersection is less than 0.01 cm which is adequate for this antenna/frequency.

2.4 ALIGNMENT OF PROBE AXIS ALONG THE Z-AXIS

It can now be determined if the probe is aligned with its axis coincident with the axis of rotation of the polarizer. The probe is rotated 180 deg. by the polarizer, and the alignment data is re-measured. If the probe is correctly aligned, the amplitude and phase difference plots will not change. If it is not aligned, both curves will show a change in the slope of the difference curves due to the offset of the probe in the x-direction. The offset can be determined either from the curves or by moving the probe in x and repeating the measurement until the curve is flat again. The probe can then be rotated in azimuth relative to the polarizer rotator until no change is observed. The correct rotation of the probe in elevation is found with a similar test, except that the probe and the AUT are rotated 90 degrees about their axes before acquiring alignment data.

2.5 Y-ZERO ERROR

It was noted in Section 2.1 that the electrical tests are not sensitive enough to distinguish between non-orthogonality errors and y-zero errors. Both errors translate the probe in y from the φ-axis. The result is that, in both cases, φ-scans shown by the dashed lines in Fig. 7, are not centered on the antenna's z-axis. By aligning the orthogonality with the optical or mechanical procedures, only the y-zero error remains.

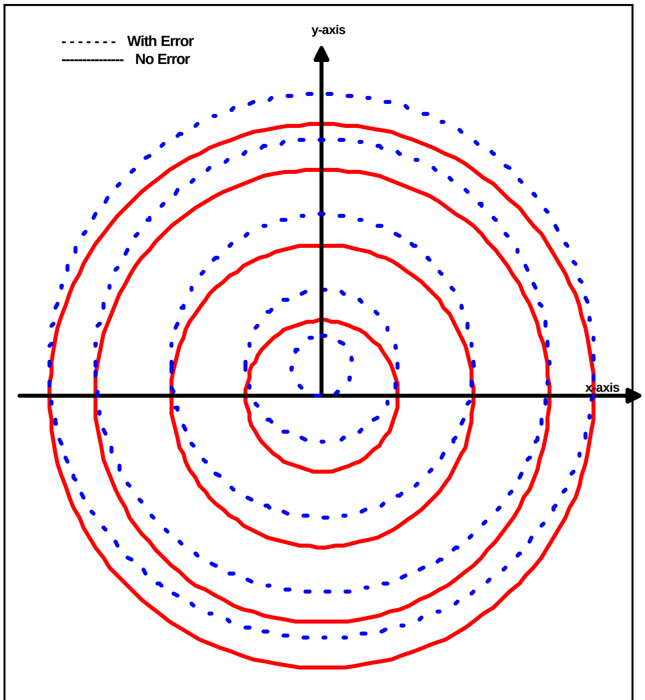

Figure 7 Trace of j-Scans in the X-Y Plane due to Non-Orthogonality or Y-Zero Error.

There are electrical tests that can detect the y-zero alignment error, but for most antennas whose near-field patterns are fairly symmetric in the region close to the z-axis, the tests will not detect small errors. This limitation can be overcome by either using an antenna such as a difference pattern that has a complex field pattern close to the z-axis or temporarily mounting the antenna in an offset position to produce a complex pattern. Both approaches have been tried with good success. The X-band horn was first offset by about 2.5 inches from the φ-axis so that as it rotated in φ, it described a circle rather than rotating about its axis. This essentially translated the horn along the x-axis of the measurement sphere, and the size of the minimum sphere was therefore increased. The pattern was then not symmetric about the z-axis.

For any non-symmetric antenna pattern, there are three different tests that can be used to detect y-zero alignment errors. The first makes use of the same test described above where θ-scans are taken for φ = 0 and 180 deg. The y-zero error is indicated by the fact that the amplitude difference curve does not pass through zero at θ = 0 as shown in Fig. 8 for the offset horn. The y-zero error was 0.065 in for this data, and the y-alignment was unchanged from Figs. 3 and 6. The offset position of the horn made the data more sensitive to this error.

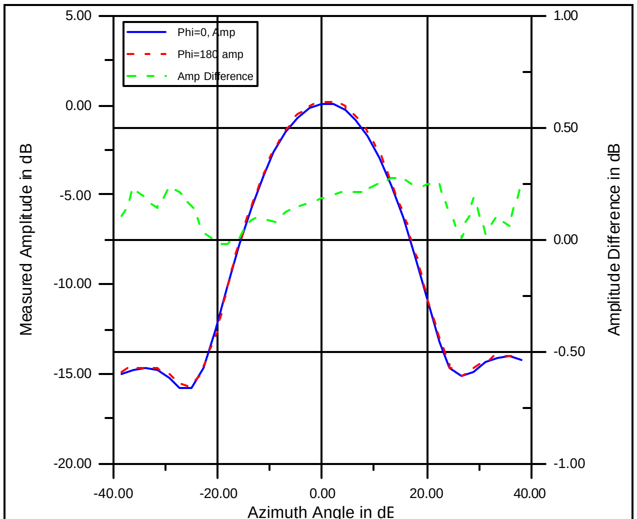

Figure 8 Measured Amplitude and Amplitude Difference Showing Effect of Y-Zero Error.

A second measurement also shows the effect of this error. This measurement compares a φ-scan taken at θ = 0 where the antenna is rotated about the φ-axis with a polarization scan where the probe is rotated about its axis. If there is no y-zero error, these two should produce identical data. If there is a y-zero error, the polarization scan will be taken at a point on the measurement sphere, while the φ-scan will describe one of the dashed circles shown in Fig. 7. A sample of this measurement is shown in Fig. 9 for a difference pattern antenna with a y-zero error of 0.35 in. Both Figs. 8 and 9 clearly indicate an alignment error, but it is difficult to quantify the error from the measured data. The correct setting for the y-position of the probe is found by taking a series of measurements for different y-positions and noting the convergence of the curves towards zero crossing in Fig. 8 and identical curves in Fig. 9. Since the scans can be taken and plots produced in just a few minutes, this process can be done fairly quickly.

The process can be speeded up with the third type of measurement, if the probe is mounted on a planar scanner. Two "mini-planar-scans" can be taken over a few inches around the z-axis for φ = 0 and φ = 180 deg. and contour

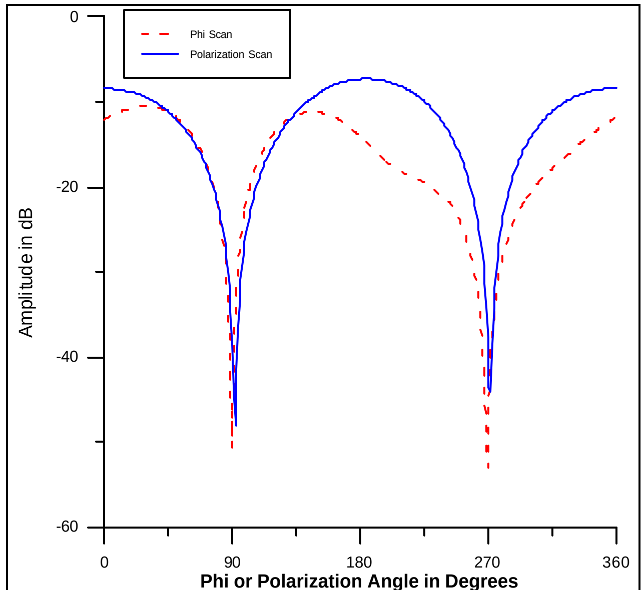

Figure 9 Measured Amplitude on a Difference Pattern Antenna for j-Scan and Polarization Scan Showing Effect of Y-Zero Alignment Error.

plots of either the amplitude or phase produced. Comparison of these two contour plots will quickly quantify the y-zero error as well as any residual x-zero error. Two sample contour plots are shown in Figs. 10 and 11. The y-zero offset is found by rotating Fig. 11 180 degrees about the origin and translating it in x and y until the contours in Figs. 10 and 11 match. In this case Fig. 11 was translated 0.7 inch in the y-direction which is twice the y-zero offset. After the probe was reset, the tests shown in Figs. 8-11 were repeated to verify correct alignment.

3. VERIFYING THE ALIGNMENT TECHNIQUES

We have used two approaches to verify the alignment techniques. The first was a comparison of the results of complete spherical measurements on the X-Band Horn in both the on-axis position and offset by 2.5 inches. The spherical results in the offset position are very sensitive to all the alignment parameters. The good comparisons demonstrated that the alignment was indeed correct. A more rigorous test of the alignment procedures involved checking the alignment with an optical autocollimator and precision level. The results of these comparisons will be presented in the talk.

4. Conclusions

A series of electrical tests have been developed that can be used to align and check the alignment of a spherical near-field rotator. They are fast and accurate and built into the NSI Spherical software. The θ-zero and non-intersection errors were used successfully in the field for fine alignment of the NSI system installed in China. This system is the subject of a companion paper being presented in the poster sessions.

Some of the NSI spherical systems are designed to be portable, and the ability to rapidly set up the scanner and perform electrical tests for the alignment enhances the usability and accuracy of the system. The authors are planning additional tests and refinements to the techniques described in this paper

The sensitivity of the tests may be a good indication of how critical an alignment parameter is. For instance, if the antenna pattern is fairly symmetric about the z-axis, the test is quite insensitive to y-zero alignment errors. This may indicate that this error is relatively unimportant for such antennas, but this needs to be verified.

The tests have some limitations. We cannot distinguish between θ-zero and x-zero errors, nor can we distinguish between orthogonality and y-zero errors. Because of this, some additional alignment procedures must be used that sets one of each pair of these parameters.

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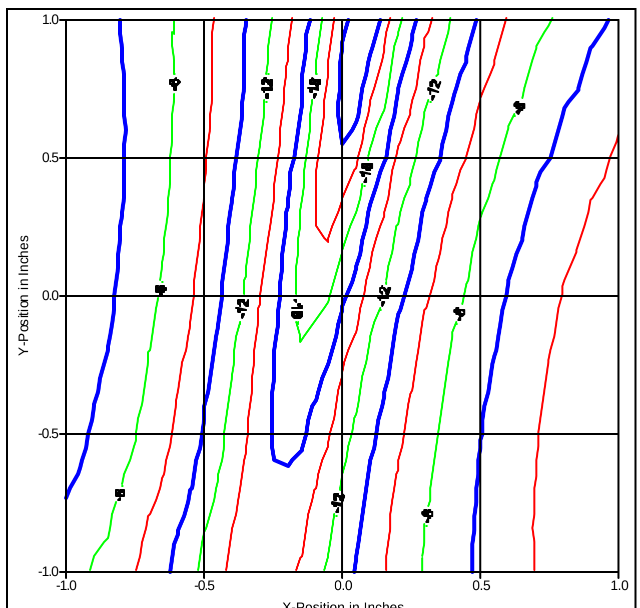

Figure 11 Planar "Mini-Scan" for j = 180 on Difference Pattern Antenna with .35 inch Y-Zero Error.

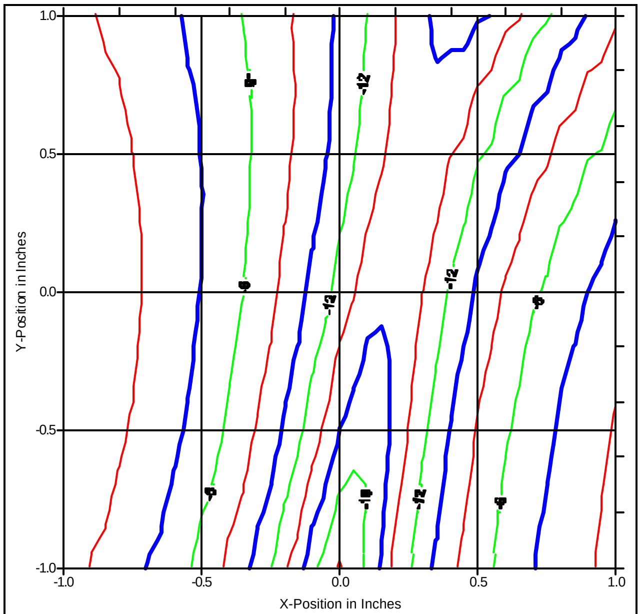

Figure 10-Planar "Mini-Scan" for j = 0 on Difference Pattern Antenna with 0.35 inch Y-Zero Error.