High Accuracy Spherical Near-Field Measurements On a Stationary Antenna

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ABSTRACT

Most conventional spherical near-field scanning systems require the antenna under test to rotate in one or two axes. This paper will describe a novel rolling arch near-field scanner that transports a microwave probe over a hyper-hemispherical surface in front of the antenna. This unique scanning system allows the antenna to remain stationary and is very useful for cases where motion of the antenna is undesirable, due to its sensitivity to gravitational forces, need for convenient access, or special control lines or cooling equipment. This allows testing of stationary antennas over wide angles with accuracies and speeds that historically were only available from planar near-field systems.

The probe is precisely positioned in space by a high precision structure augmented by dynamic motion compensation. The scanner can complete a hyper-hemispherical multi-beam, multi-frequency antenna measurement set of up to eight feet in diameter in less than one hour.

The design challenges and chosen techniques for addressing these challenges will be reviewed and summarized in the paper.

Keywords: Spherical Near-field, Accuracy, Position Correction

1. Introduction

Nearfield Systems Inc. (NSI) has developed a new spherical near-field scanner, NSI-700S-300, that is capable of testing stationary antennas over wide angles with accuracies and speeds that historically were only available over narrow angles with planar near-field systems. The scanner is ideal for wide angle satellite and radar antenna testing. The planar near-field technique is often used for testing antennas of higher directivity (typically >15 dBi), and allows the antenna to remain in a fixed orientation. However, planar near-field scanning cannot provide good sidelobe coverage out to beyond about ±70°. Spherical near-field measurement systems can avoid that limitation, but until now have required that the antenna be moved about one or both axes to accomplish the measurement. The NSI-700S-300 Arch Roll Spherical Near-field Scanner, has overcome this limitation, allowing high precision spherical near-field measurements beyond ±90 degrees, without the need to move the antenna (see Figure 1).

Figure 1 - NSI-700S-300 arch roll spherical scanner

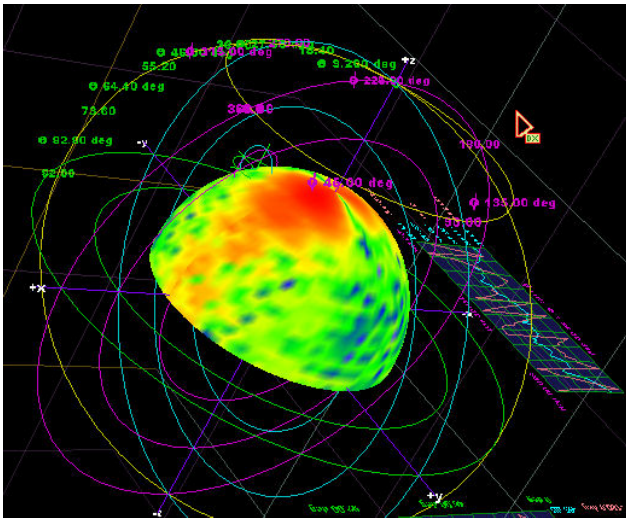

Figure 2 - Typical hyper-hemispherical near-field data measured on NSI-700S-300

The challenge was to design a spherical antenna measurement system that would allow fast and accurate electromagnetic field measurements for a stationary antenna by using only probe motion. The advantages of testing a stationary antenna include:

• The antenna can be measured in the orientation in which it will be used. This way antenna flexure due to a changing gravity vector does not corrupt the measured patterns.

• Test fixture support hardware costs for the antenna can be greatly reduced. For instance, expensive slip ring assemblies to support power & control cabling as well as thermal control supply lines are no longer necessary.

• The antenna alignment support equipment is much simpler and can be set up in the manufacturing assembly area, and simply rolled in to the test range without elaborate fixtures, mounting procedures, or alignment steps.

2. System Description

The stationary antenna approach requires an electromagnetic field sensing probe that moves over a hyper-hemispheric surface enveloping the antenna (see Figure 2). The probe is precisely positioned in space by a high precision structure augmented by dynamic motion compensation. The scanner can complete a hyper-hemispherical multi-beam, multi-frequency antenna measurement set of up to eight feet in diameter in less than one hour. The arch rotates continuously at 30 degrees per second during the measurement process.

Figure 3 - NSI-700S-300 arch roll spherical scanner during factory testing

The new Arch Roll scanner design not only eliminates the need for slip ring assemblies to the antenna, but simplifies the meticulous alignment procedure required for accurate measurements on traditional spherical near-field scanners.

The design is ideally suited for satellite and radar antennas that require precision testing of a fixed antenna that cannot be moved or rotated during a test cycle.

Other unique features of the Arch Roll Scanner include:

* Precision encoders on the Theta and Phi rotation axes

* A 4" travel radial stage for performing dynamic position correction, and for accommodating a variety of probes lengths.

* Specially designed algorithms for dynamic probe position correction of the arch roll configuration that allow 'on-the-fly' probe position correction to maintain a probe position accuracy on the order of 0.003 inches and 0.003° rms.

* An RF subsystem that is capable of measuring thousands of frequencies and beam configurations.

The NSI-700S-300 Arch Roll Spherical Near-field Scanner together with NSI's Panther 9000 RF subsystem and NSI 2000 antenna measurement software deliver spherical measurements with unprecedented accuracies and speeds.

The following table summarizes the mechanical axes on the system.

Axis	Travel	Speed	Resolution
Theta	±95°	2°/s	0.00032°
Phi	360°	30°/s	0.00027°
Radial	4”	0.5 in/s	0.00008”

Table 1 – Mechanical Axes on Scanner

3. System Accuracy Requirement

Spherical near field system alignment sensitivity to various alignment errors have been studied in [1] and [2]. The design requirements from NSI’s customer were to position a microwave probe over a hyper-hemispherical surface to less than 0.003” rms in X, Y and Z. To achieve this accuracy, NSI designed the system to be based on a custom Phi rotation stage, combined with a rotating Theta Arch with ±95° probe travel. The Phi rotator is designed with two bearings at 36” spacing and radial runout on the order of only 0.0003” which minimizes its contribution to the probe positioning accuracy. The Phi stage is mounted on top of an 8’ tall pedestal to position its rotation axis at the center of the test range.

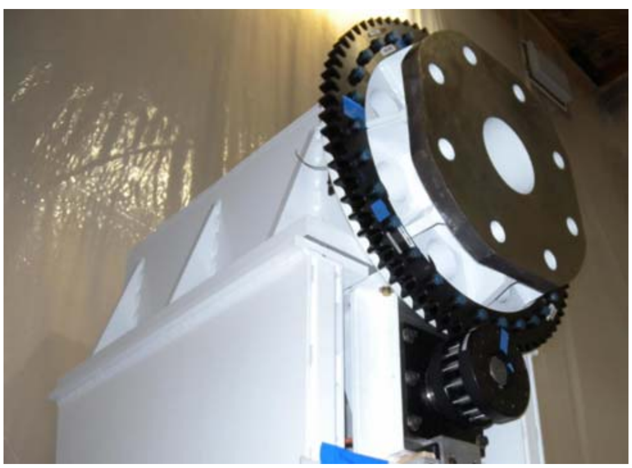

Figure 4 –Phi rotator on pedestal

To mount and align the large Theta C-shaped structure, a special set of XY translation and spherical shaped interface fixtures were designed as shown in Figure 5. This fixture allowed us to precision align the C-shaped structure in the 3 degrees of freedom required to meet the required intersection and orthogonality at the Theta-zero position.

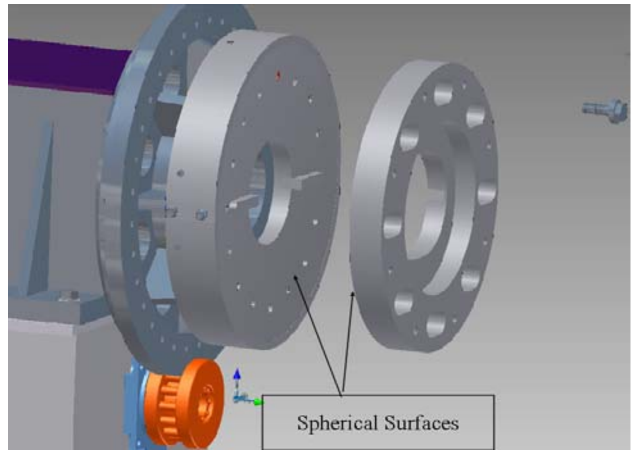

Figure 5 – Spherical adjustment fixture for mounting and aligning Theta structure to Phi stage

The Theta structure was designed as two welded steel sections bolted together at the hub and then attached to the Phi stage. The structural analysis of the stage was conducted with Ansys, and optimized for best stiffness and minimum deflection. The “C” structure deflection due to its own weight are under 0.020” under all orientations, and less than about 0.040” fully loaded with rails, absorber, and the moving probe load. See Figure 6 for an example of the structure analysis for one of the unloaded cases.

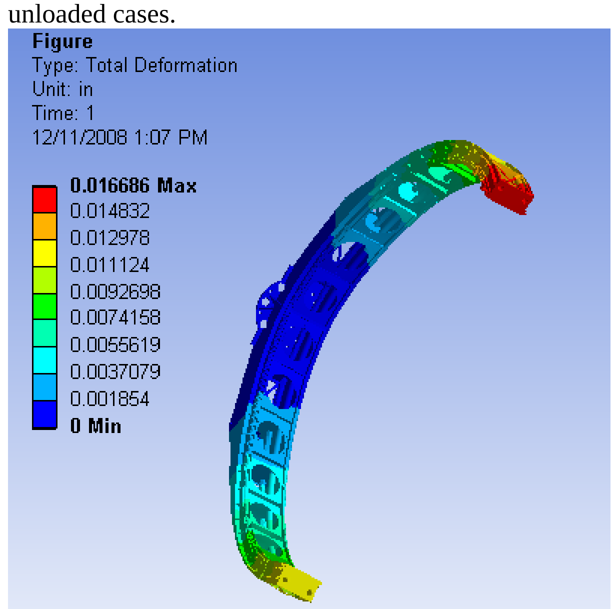

Figure 6 –Theta Stage Structural Analysis

The Theta carriage is designed to ride on the two curved bearings on either side of the Theta “C” structure, and is driven from one side with a stepper motor and gear reducer (Figure 7).

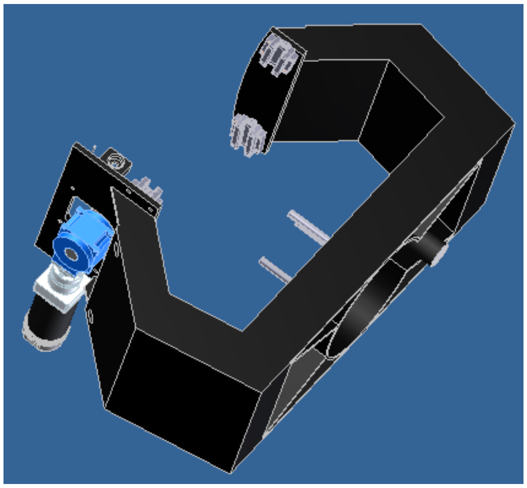

Figure 7 – Theta Carriage for Probe Motion

4. Design Challenges

During assembly of the scanner, NSI made extensive use of a laser tracker to confirm system alignment tolerances could be met. Figure 8 shows the result of a check of the radius during factory assembly. The laser tracker software can show magnified color-coded highs and lows in the measured data, allowing assemblers to easily iterate the alignment to meet the requirement. In this case, the radius error over the full travel was adjusted to < 0.0007" rms.

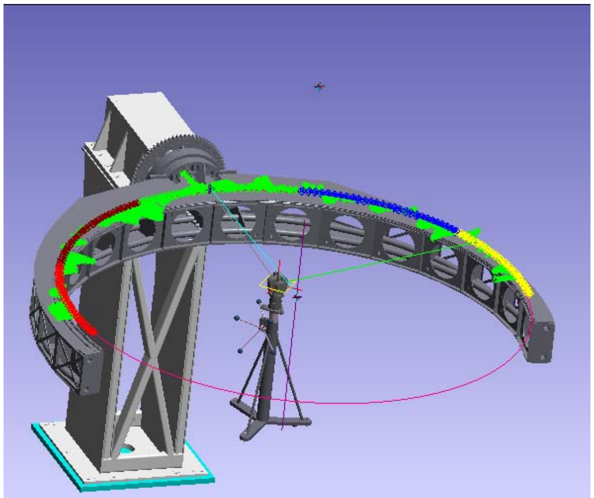

Figure 8 – Laser tracker metrology during system assembly & alignment

The laser tracker is also used for the 2-dimensional system alignment and verification. Figure 9 shows the cluster of measurement points at 5° increments in theta and phi over the hemisphere

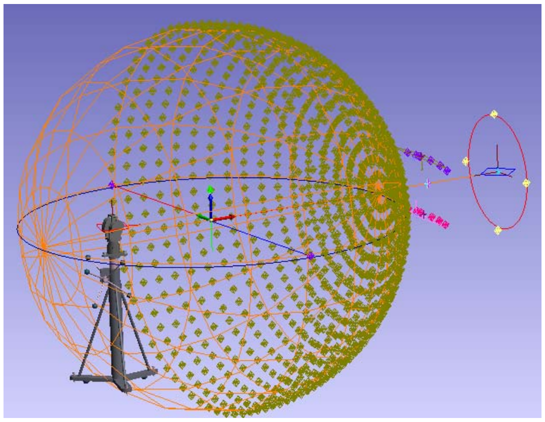

Figure 9 – Laser tracker measurements over 360° Phi and ±90° Theta

5. Correction Technique

To correct for expected manufacturing tolerances and gravitational deflections in the scanner structure, NSI implemented a dynamic correction scheme similar to those used in NSI's conventional planar near-field scanners, described in [3]. In the spherical near-field scanner case, we chose to implement a dynamic 3-axis correction model that adjusts the Radius, Theta and Phi axes on-the-fly while the scanner theta and phi axes are in motion.

The laser tracker map of scanner errors was converted into a set of Position correction coefficients that are downloaded into the FPGA-based Panther Motion Controller for precision motion control. During the typical measurement process, the structure will be rotating in Phi at 30°/sec, with the Theta and Radius stages performing small correction moves dynamically as the structure rotates. The Panther receiver is triggered by the Phi angle target positions adjusted by the Phi encoder and Phi structure error corrections. This dynamic correction process eliminates the need to apply any post processing position corrections to the data, and yields the maximum accuracy in the RF test results.

6. Measured Results

The measured results were obtained from a 5° spacing dataset in theta and phi, similar to that shown in Figure 9. The uncorrected data is shown in Figure 10 & Figure 11 for the radius error and the corrected data is shown in Figure 12 & Figure 13.

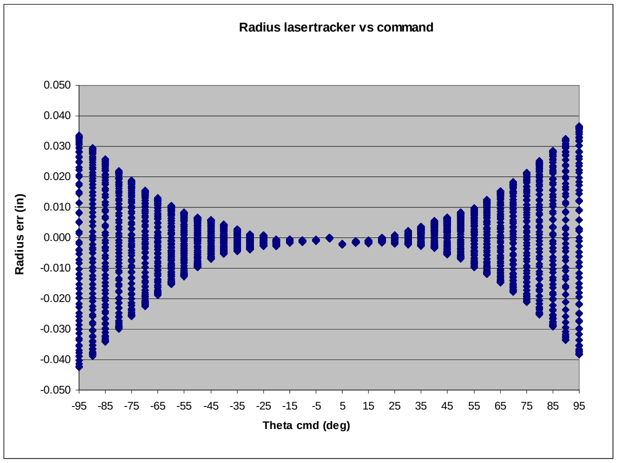

Figure 10 – Laser tracker measurements of <u>uncorrected</u> Radius error over ±95° Theta for all Phi angles

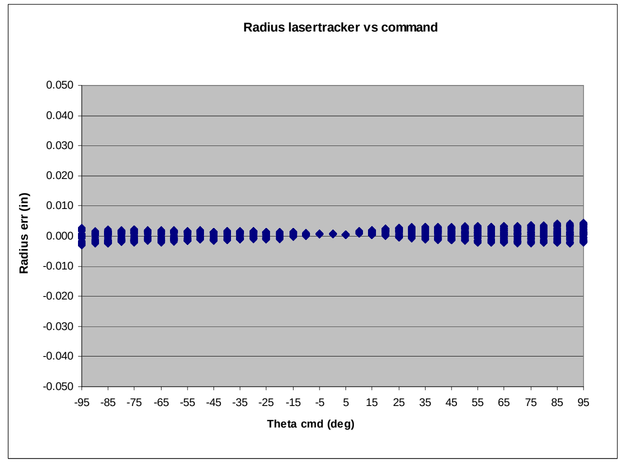

Figure 12 – Laser tracker measurements of <u>corrected</u> Radius error over ±95° Theta for all Phi angles

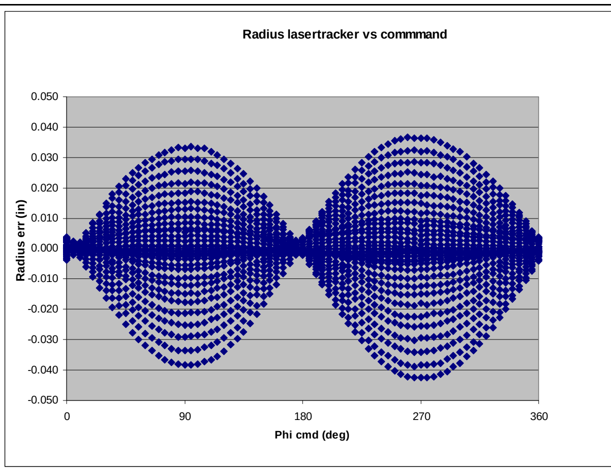

Figure 11 – Laser tracker measurements of <u>uncorrected</u> Radius error over 360° Phi for all Theta angles

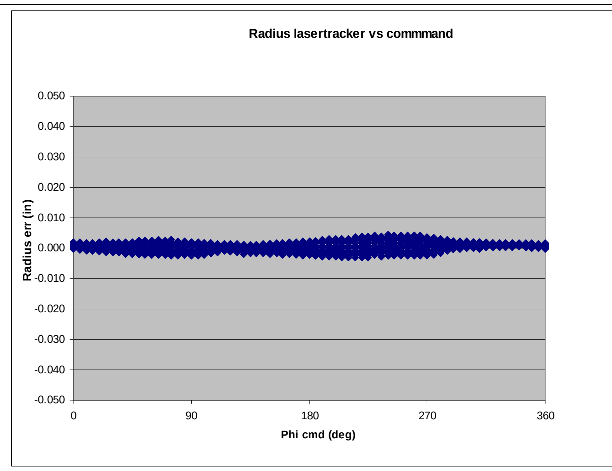

Figure 13 – Laser tracker measurements of <u>corrected</u> Radius error over 360° Phi for all Theta angles

	Uncorrected Position Error		
	R	Theta	Phi
	(in)	(deg)	(deg)
p-p	0.076	0.034	0.151
rms	0.010	0.005	0.018

Table 2– <u>Uncorrected</u> Position Error

	Corrected Position Error		
	R	Theta	Phi
	(in)	(deg)	(deg)
p-p	0.007	0.009	0.042
rms	0.001	0.002	0.003

Table 3– <u>Corrected</u> Position Error

Similar results were archived in correcting the theta and phi errors. The resulting uncorrected and corrected errors are summarized in tables 2 & 3. All the error sources have been reduced significantly, and the Radius error has been reduced by an order of magnitude.

7. Summary

This paper has summarized the advantages of the use of a novel spherical near-field scanner which allows the Antenna Under Test to remain stationary, and has also summarized some of the key design details of the scanner. The correction capability of the dynamic correction software has been demonstrated to reduce the probe position errors to less than 0.003” rms and also less than 0.003° rms over the entire hyper-hemispherical scanning surface.

8. REFERENCES

[1] Newell, A. C., Hindman, G., "Quantifying the effect of position errors in spherical near-field measurements", In the proceedings of the 20th annual AMTA Meeting and Symposium, pp 145-149, Montreal, Canada, 1998.

[2] Newell, A.C., Hindman, G. Stubenrauch, C., "The effect of measurement geometry on alignment errors in spherical near-field measurements", AMTA 21st Annual Meeting & Symposium, Monterey, California, Oct. 1999.

[3] Hindman, G., “Position Correction On Large Near-Field Scanners Using An Optical Tracking System” AMTA 16th Annual Meeting & Symposium, Long Beach, California, Oct. 1994.