SPHERICAL NEAR-FIELD SELF-COMPARISON MEASUREMENTS

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ABSTRACT

Spherical near-field measurements require an increased level of sophistication and care to achieve accurate results. This paper will demonstrate an automated set of self-comparison tests, which can be used for establishing and optimizing a spherical system's performance. An over-determined set of measurements can help to qualify positioner alignment, range reflection levels, truncation effects, and additional parameters of interest. These results will help in optimizing the test configuration to achieve accurate near-field measurement results.

Keywords: Antenna Measurements, Near-field, Spherical, Error Analysis

1.0 Introduction

The objective of this paper is to define a series of steps necessary to insure accurate spherical near-field measurements. Through careful combination of initial measurement setups including acquisition of redundant data and selective processing, one can almost automatically derive the expected test accuracy for many of the key parameters. One key element of the process is to use a mechanical scanner capable of full 360° rotation in theta and phi, which allows you to acquire two complete spheres of data on the antenna under test with each sphere of data constructed by a different combination of angles from the two rotators. The sequence of steps is:

1. Check the scanner system alignment
2. Mount Antenna Under Test (AUT) and check electrical alignment
3. Set up RF configuration for maximum dynamic range and SNR
4. Optimize scan speed and test parameters to achieve desired data
5. Acquire redundant data
6. Analyze redundant data to derive system errors
7. Correct any identified errors
8. Choose final test parameters for upcoming tests

Through this series of tests and processing, largely automated through the NSI 2000 software's scripting capability, a high confidence of the measurement accuracy for a test campaign can be assured with a minimal effort.

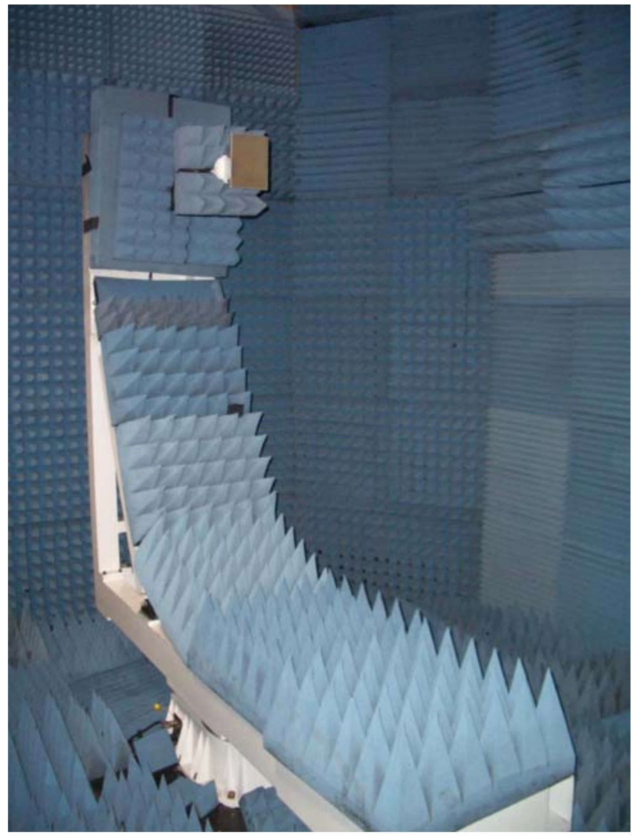


Figure 1 – NSI 700S-60 Spherical Near-field Scanner shown testing a WR-159 Standard Gain Horn

2.0 Measurement System Configuration

Figure 1 shows a WR-159 Standard Gain Horn mounted to the phi stage of NSI's medium sized 700S-60 near-field system. The phi stage and L-bracket is mounted to the azimuth stage, which provides the theta motion. The combination of phi and theta motion allows measuring full spherical near-field measurements in the theta-phi geometry. The probe used is a WR-159 Open-ended Waveguide Probe (OEWG), mounted to a pol rotator allowing acquisition of E-theta and E-phi components.

The alignment of the spherical phi and theta rotators is critical for accurate measurements, and we used NSI's electrical alignment procedure [1] [2], which allows a check of the rotator mechanical alignment with the AUT installed.

The RF configuration is a Panther 6000 receiver with a pair of 20 GHz Panther 7020 RF Sources, and an external mixer system. For most of the testing, the system was set to take 44 frequencies with 20-microsecond frequency switching time. For multi-frequency spherical near-field measurements, the position error induced by taking data on the fly during bi-directional measurements is influenced by many factors:

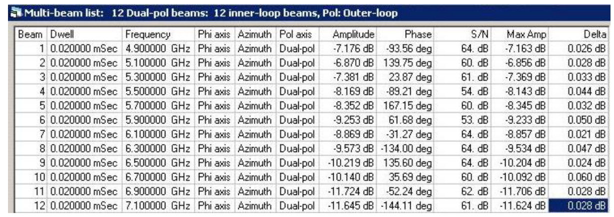
- scan speed
- number of frequencies
- frequency switching speed
- receiver integration time

For this testing, we chose to set the receiver integration time to 355 usecs (100 averages) to yield about 60 dB Signal to Noise Ratio (SNR) on the near-field beam peak. We then chose to control the 'beam smear' (total angular travel for the entire 44 beam multi-frequency beam set) to be less than ±.16°. This forced the scanner to reduce from its maximum scan speed of 40 degrees per second to 0.32 / (.000355 + 0.000020) * 44 = 20 deg/sec, or about half speed. To satisfy the spherical near-field sampling criteria, we sampled 3° spacing in theta and phi, yielding 121 points in theta and phi for a full redundant data set with 2 polarizations. Total test time for this 44-frequency configuration is 50 minutes for a complete spherical data set, and 100 minutes for a fully redundant data set (cutting the number of frequencies in half or accepting a larger beam smear would cut the test time to about 25 minutes).

A summary of the test configuration is as follows:

AUT	NSI-RF-SG159 (SGH)
Probe	NSI-RF-WR159 (OEWG Probe)
RF subsystem	Panther 6000/7020 (0.1 - 20 GHz)
Integration time	355 usecs (100 averages on Panther)
Frequency switching time	20 usecs (NSI Panther 7020)
Theta/Phi sampling	3°
Maximum beam-set 'smear'	±.16°
Phi scan speed	20 deg /sec (Slowed from max of 40 deg/sec)
Phi scan	360°
Theta scan	360°
Test time	100 minutes (50 min non-redund.)

Figure 2 shows a snapshot of the live Inner Loop Timing (ILT) display taken at the near-field beam peak. This display shows the operator the test scenario for a single beam set and also shows live amplitude and phase readings during the fast inner loop scanning. A statistical analysis using NSI's SNR subroutine gives the Signal to Noise Ratio, and we also display the peak-to-peak amplitude of the signal. This live display is extremely valuable during measurement setup to verify system operation and adequate S/N.


Multi-beam list: 12 Dual-pol beams: 12 inner-loop beams, Pol: Outer-loop

Beam	Dwell	Frequency	Phi axis	Azimuth	Pol axis	Amplitude	Phase	S/N	Max Amp	Delta
1	0.020000 mSec	4.900000 GHz	Phi axis	Azimuth	Dual-pol	-7.176 dB	-93.56 deg	64. dB	-7.163 dB	0.026 dB
2	0.020000 mSec	5.100000 GHz	Phi axis	Azimuth	Dual-pol	-6.870 dB	139.75 deg	60. dB	-6.856 dB	0.028 dB
3	0.020000 mSec	5.300000 GHz	Phi axis	Azimuth	Dual-pol	-7.381 dB	23.87 deg	61. dB	-7.369 dB	0.033 dB
4	0.020000 mSec	5.500000 GHz	Phi axis	Azimuth	Dual-pol	-8.169 dB	-89.21 deg	54. dB	-8.143 dB	0.044 dB
5	0.020000 mSec	5.700000 GHz	Phi axis	Azimuth	Dual-pol	-8.352 dB	167.15 deg	60. dB	-8.345 dB	0.032 dB
6	0.020000 mSec	5.900000 GHz	Phi axis	Azimuth	Dual-pol	-9.253 dB	61.68 deg	53. dB	-9.233 dB	0.050 dB
7	0.020000 mSec	6.100000 GHz	Phi axis	Azimuth	Dual-pol	-8.869 dB	-31.27 deg	64. dB	-8.857 dB	0.021 dB
8	0.020000 mSec	6.300000 GHz	Phi axis	Azimuth	Dual-pol	-9.573 dB	-134.00 deg	64. dB	-9.534 dB	0.047 dB
9	0.020000 mSec	6.500000 GHz	Phi axis	Azimuth	Dual-pol	-10.219 dB	135.60 deg	64. dB	-10.204 dB	0.024 dB
10	0.020000 mSec	6.700000 GHz	Phi axis	Azimuth	Dual-pol	-10.140 dB	35.69 deg	60. dB	-10.092 dB	0.060 dB
11	0.020000 mSec	6.900000 GHz	Phi axis	Azimuth	Dual-pol	-11.724 dB	-52.24 deg	62. dB	-11.706 dB	0.028 dB
12	0.020000 mSec	7.100000 GHz	Phi axis	Azimuth	Dual-pol	-11.645 dB	-144.11 deg	61. dB	-11.624 dB	0.028 dB

Figure 2 – Live Multi-frequency display at 20 usec switching time

3.0 Redundant Data Test Scenario

Using a phi over theta mechanical scanning system for spherical measurements, one can choose two different methods of acquiring the data. The first method, which we will call '180phi' involves rotating the AUT in phi from 0° to 180°, and then taking both + and - data in theta. In the second method, which we will call '360phi', the AUT is rotated the full 360° in phi, and then it is only required to take one-sided theta data - 0° to 90° for a hemisphere of data, or 0° to 180° for a full sphere. The second method is often preferred, since the phi axis can usually be rotated faster than the theta axis, which is moving more mass. Also since you are moving the stage a full 360°, you can take advantage of running it continuously in the same direction, which can significantly reduce test time and potential bi-directional errors. Each method has a different sensitivity to chamber and alignment errors, and each can have advantages over the other [3].

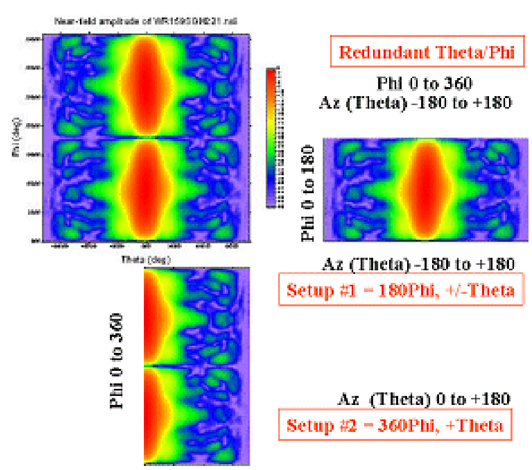


Figure 3 - 360 phi vs. 180 phi data format

In Figure 3, we show a fully redundant dataset acquired with 360° phi rotation and +/-90° theta rotation. The figure also shows which sections out of the redundant dataset make up a normal 360phi or 180phi dataset.

Taking a full dataset over 360° phi and 360° theta will take twice as long, but will allow a good estimation of the following errors:

1. repeatability
2. 360° phi vs. 180° phi geometries
3. reflections from sidewalls of the chamber
4. truncation

4.0 Measurement Results

REFLECTIONS

During the electrical alignment tests, we are comparing a near-field azimuth cut with AUT at PHI=0° and another azimuth cut with PHI=180°. The electrical alignment analysis focuses on the comparison of amplitude and phase errors near the peak of the beam, however if during the same test we broaden the angular span to ±180°, we can compare the near-field amplitude patterns taken at PHI=0° and PHI=180°. The differences in the near-field sidelobes will help identify reflections in the chamber. As the azimuth stage is rotated, the main beam from the horn illuminates the chamber sidewalls, reflecting into the probe and corrupting the direct measurement path. In the result in Figure 4, we can see an error level of about –40 dB which can serve as a first approximation of the reflection level (NIST term 16).

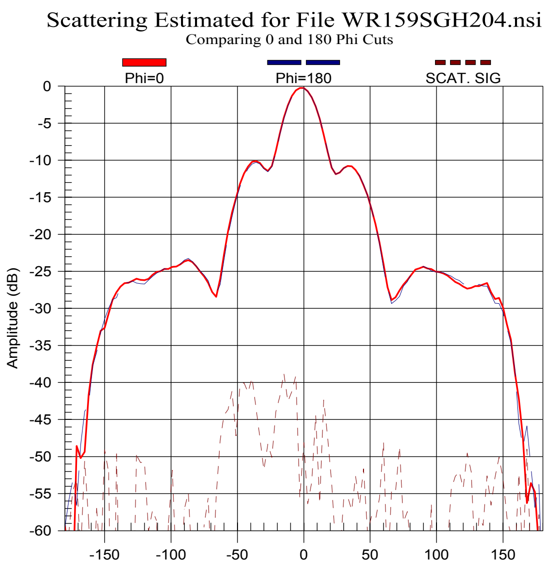


Figure 4 – Near-field scattering test checking chamber sidewalls

RANDOM ERRORS

Prior to far-field system comparisons, two complete redundant datasets are acquired and compared to insure the system's overall repeatability. The subtraction of the two far-field azimuth patterns shows a residual error of about –57 dB (Figure 5), so this represents the random noise term in the uncertainty budget (NIST term 18).

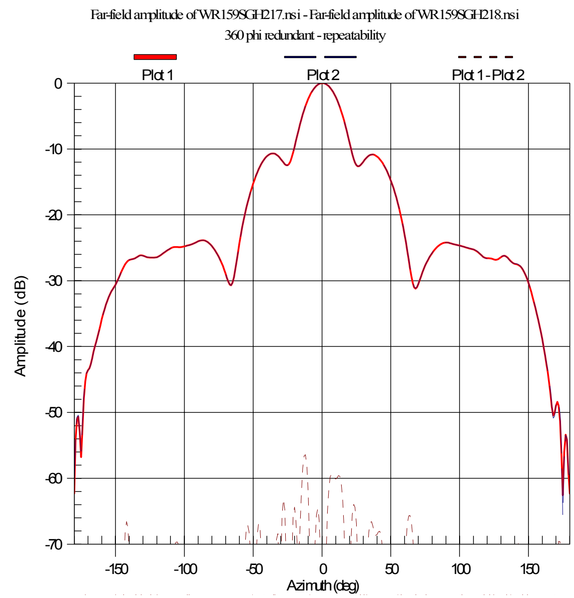


Figure 5 – System repeatability, comparing two redundant datasets

MEASUREMENT GEOMETRY

The post-processing of the double redundant data will automatically compare the results of the 360phi data versus the 180phi data, versus the average of the entire redundant dataset. Figure 6 shows a comparison between the 3 data sets.

A closer look at the first and second sidelobes is shown in Figure 7. The first averaged data is seen to fall between the 360phi and 180phi curves as expected. The first sidelobe error is about ±0.15 dB at around –11 dB, and the second sidelobe error is about ±0.25 dB at around –25 dB. At this point, the user can choose to accept the uncertainty as estimated and continue taking only non-redundant data, or can choose to take the additional measurement time to improve accuracy by the averaging of the data from the two measurement geometries. (Note that this test also includes some component of random errors and range reflection errors as well as the effect of measurement geometry).

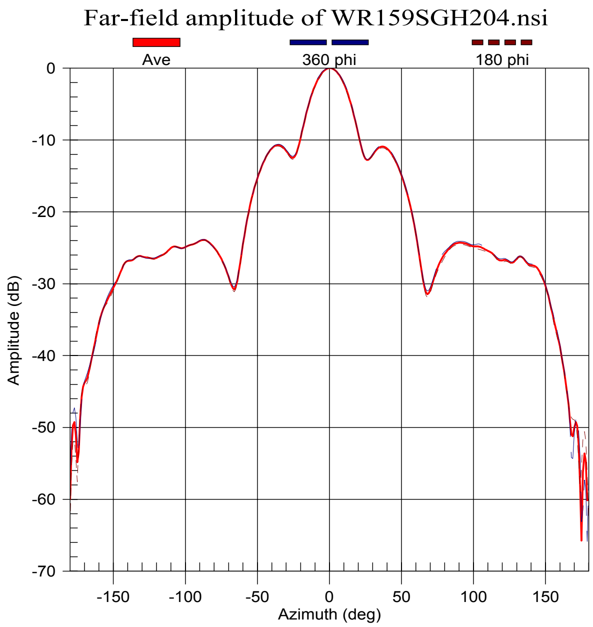


Figure 6 – 3 Processed data from redundant datasets

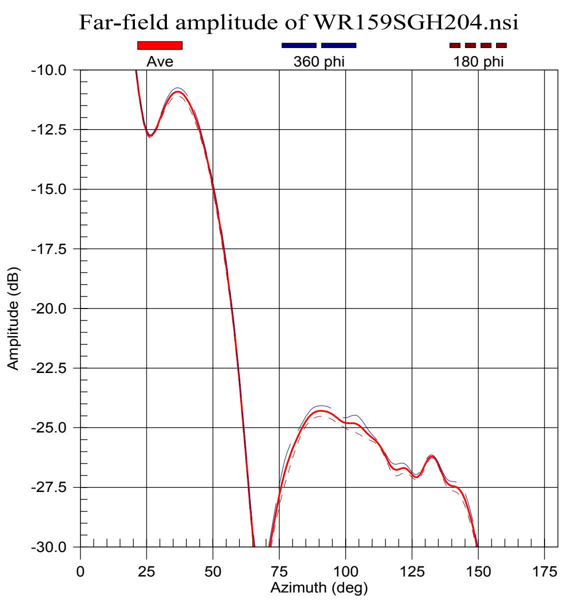


Figure 7 – Magnified look at sidelobes

TRUNCATION

The full dataset can also be analytically truncated to determine the effect on sidelobe level of taking less than a full sphere of data. Figure 8 shows the result of truncating the dataset to both ±120° and ±135°. Assuming we choose to truncate to only ±120°, we will be accepting a sidelobe error of about ±0.1 dB in the second sidelobe at the –25 dB level. This compromise will save about 1/3 of the total test time, which could be a good trade.

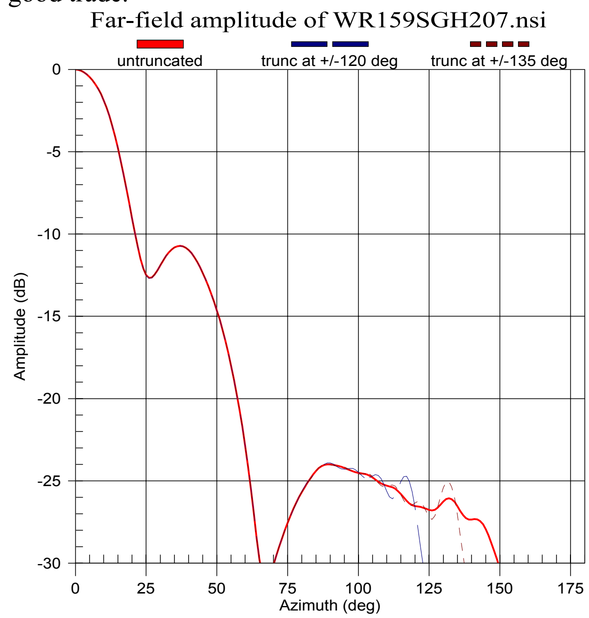


Figure 8 – Truncation affect on second sidelobe

5.0 Directivity Results

As a final system confidence check, we can process the measured multi-frequency data on the Standard Gain Horn and compare its directivity to the calculated values based on the horn's physical parameters. Figure 9 shows the comparison of a 44-frequency data set over the full WR-159 waveguide band. The average difference from measured directivity to calculated is 0.30 dB, which is well within the nominal ±0.5 dB uncertainty of the un-calibrated Standard Gain Horn.

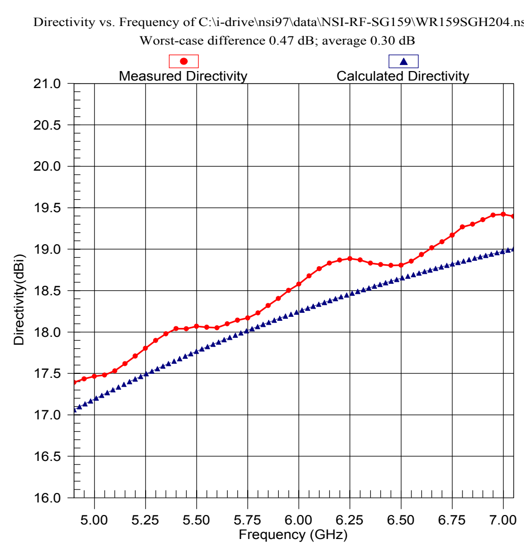


Figure 9 – Comparison of a 44-frequency data set over the full WR-159 waveguide band

6.0 Conclusion

We have shown a number of simple tests, which can rapidly help to qualify the performance of a spherical near-field range. From the data shown above, we can summarize the following 4 terms out of the NIST 18-term uncertainty budget:

NIST Term	Description	Signal to Error ratio (dB)	Error on -20dB sidelobe (dB)
7	AUT Alignment Error	-51	0.25
9	Measurement truncation	-59	0.10
16	Room Scattering	-40	0.92
18	Random Errors	-60	0.09
	RSS of these 4 terms		0.96

The tests are easy to conduct and the results can be derived largely from automatic processing of one or two doubly redundant data sets. Analysis of the results can quickly help the antenna engineer optimize accuracy vs. test time.

7.0 References

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