COMBINATION PLANAR, CYLINDRICAL, FAR-FIELD AND DUAL SPHERICAL NEAR-FIELD TEST SYSTEM FOR 0.2 – 110 GHz APPLICATIONS

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Abstract* — Nearfield Systems Inc. (NSI) has been contracted by the Department of Electrical and Computer Engineering of the University of Waterloo to install a unique antenna test system with multiple configurations allowing it to characterize a wide variety of antenna types over a very wide bandwidth. The system employs a total of 10 positional axes to allow near-field and far-field testing in various modes of operation with great flexibility. A 4 m x 4 m planar near-field (PNF) scanner is used for testing directive antennas operating at frequencies up to 110 GHz with laser interferometer position feedback providing dynamic probe position correction. The PNF's Y-axis can also be used for cylindrical near-field (CNF) testing applications when paired with a floor mounted azimuth rotation stage. A single phi-over-theta positioner permits both spherical near-field (SNF) testing from L-band to W-band and far-field testing down to 0.2 GHz. This positioner is installed on a translation stage allowing 1.8 m of Z-axis travel to adjust the probe-to-AUT separation. In addition, a theta-over-phi swing arm SNF system is available for testing large, gravitationally sensitive antennas that may be easily installed on a floor mounted rotation stage. In order to ensure system and personnel safety, a complex interlock system was designed to reduce the risk of mechanical interference and ease the transition from one configuration to another. The system installation and validation was completed in March 2013. We believe that this facility is unique in that it encompasses all commonly used near-field configurations within one chamber. It therefore provides a perfect environment for the training of young engineers and could potentially form the baseline of future academic test facilities. This paper will outline the technical specifications of the scanner and discuss the recommended applications for each configuration. It will also describe the details of the safety interlock system.

Keywords: Near-field, far-field, spherical, cylindrical, planar.

I. INTRODUCTION

The University of Waterloo has been successfully performing antenna measurements using an NSI-provided 1.8 m x 1.8 m planar near-field scanner since the system was installed in 2009. This scanner allows directive antennas to be measured easily and accurately from X-band up to 1.1 THz. While this system has seen extensive use, it has some fundamental limitations that the University of Waterloo had a desire to overcome:

1. The planar scanner can only be used to characterize antennas with medium to high directivity due to the finite scan size (1.8 m x 1.8 m) of the system.
2. Back hemisphere data cannot be acquired on a planar scanner without utilizing complex poly-planar near-field measurement techniques [1].
3. Antennas larger than or approaching the size of the scan plane cannot be accurately measured on this system without measurement errors due to data truncation.

In order to address these limitations, a new system was installed by Nearfield Systems Inc. in 2013. Section II will outline the design requirements presented by the University of Waterloo in order to meet all of their antenna testing needs. Next in Section III the various measurement configurations will be detailed along with some delivered performance specifications. Section IV will outline the RF sub-system that is shared among the different scanner sub-systems. Section V will discuss the interlock system that was installed to ensure equipment and personnel safety. Finally, some conclusions will be presented in Section VI.

II. DESIGN REQUIREMENTS

The Department of Electrical and Computer Engineering at the University of Waterloo was interested in acquiring a multi-purpose antenna measurement system to overcome the limitations of their existing system outlined in Section I. The new installation was required to be a combination planar, cylindrical, spherical near-field and far-field test system with built-in acquisition and processing capability. The system had to be suitable for testing antennas up to 2.5 m in diameter over the frequency range of 200 MHz to 110 GHz. The RF sub-system was based on an Agilent PNA-X VNA with remote mixers to support testing across the entire frequency range. A computer system controlling the mechanical and RF sub-systems ties all of the components together through the use of the NSI2000 Antenna Measurement Software. Table I summarizes the design requirements of the chamber and various scanner sub-systems.

TABLE I. DESIGN REQUIREMENTS

Parameter	***Delivered Capability***
Near-field Measurement Configurations	Planar Cylindrical Phi-over-theta spherical Theta-over-phi spherical
Far-Field Measurement Capabilities	Phi-over-theta spherical Dual-polarization
Frequency Range	0.2 – 110 GHz
RF Sub-system	Shared by all configurations
Number of Positional Axes	6 rotational axes 4 linear axes
Microwave Absorber	48” pyramidal on floor 48/36” pyramidal on walls/ceiling Misc. size pyramidal on scanner
Chamber Shielding Effectiveness	Meets or exceeds MIL STD 285 [2], NSA 65-6 and IEEE 299
Safety	Emergency stop switch Interlock control safety unit Fire suppression system

III. MEASUREMENT CONFIGURATIONS

The University of Waterloo antenna measurement facility contains a total of four near-field measurement configurations, along with a dual-axis far-field scanner. Figure 1 shows a rendering of the system layout. The various acquisition sub-systems will be discussed in this section.

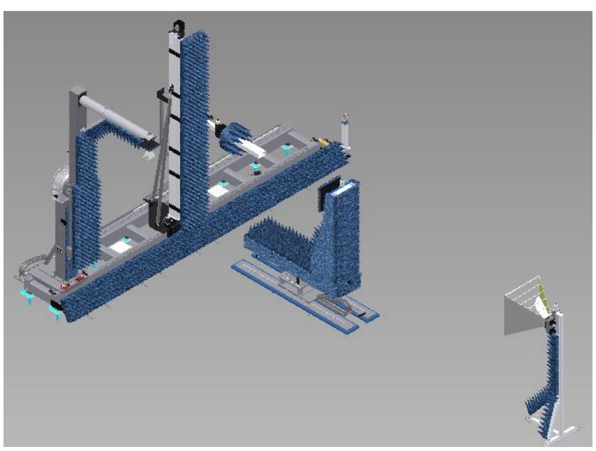

Figure 1. University of Waterloo Antenna Measurement System Layout

A. *Planar Near-Field*

The planar portion of the new combination system is a 4 m x 4 m scanner which addresses two of original system limitations outlined in section I. The planar near-field scanner can be seen in Figure 2 along with a visualization of the scan plane measured by the probe. The phi-over-theta positioner used for AUT mounting and alignment is shown in front of the planar scanner. The theta-over-phi swing arm is also visible in its “safe parking” area to prevent mechanical interference during data acquisition. Table II summarizes some of the specifications of the PNF scanner sub-system. This system is ideally suited for testing large, directive antennas.

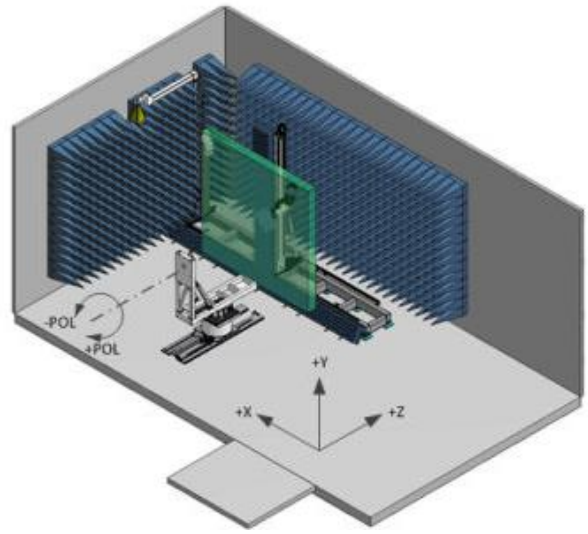

Figure 2. Planar Near-Field Scan Plane Acquired over X-Y Raster Grid; SNF Swing Arm Parked

TABLE II. PLANAR NEAR-FIELD PERFORMANCE SPECIFICATIONS

Parameter	***Delivered Capability***
Acquisition Axes	X axis, Y axis, Probe roll axis
Auxiliary Axes	Probe Z axis, AUT Z axis, AUT roll axis
Max. Scan Speed	38 cm/s
Max. Scan Plane	4 m x 4 m
Frequency Range	1 - 110 GHz
Position Accuracy	± 0.05 mm RMS
Planarity Error	< 0.07 mm RMS
Correction Capability	XYZ laser optics for position corr. [3] MTI thermal correction [4]
AUT Motion	Stationary during acquisition
AUT Mounting	Mounted on AUT roll stage for roll/Z axis adjustment
Z Axis Adjustment	25.4 cm probe translation 1.8 m AUT translation
Ideal Use	Testing large, directive antennas

B. *Spherical Near-Field*

In order to fully characterize the far-field radiation properties of antennas, one of two different SNF configurations may be used.

1) *Phi-over-Theta SNF*

The phi-over-theta SNF system shown in Figure 3 allows one to characterize antennas over a full sphere using a combination of theta, phi and polarization axes. This is especially useful when data beyond the front hemisphere is required. It also allows one to test low gain antennas that would normally suffer from severe truncation errors when tested on a PNF system.

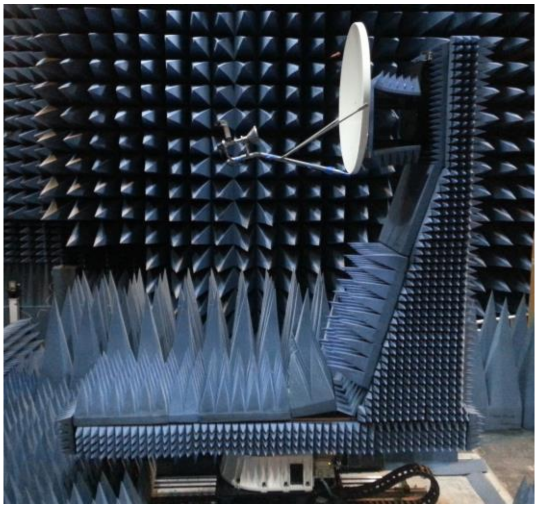

Figure 3. Reflector Antenna Mounted on Phi-over-Theta Spherical Near-Field Scanner

TABLE III. PHI-OVER-THETA SNF PERFORMANCE SPECIFICATIONS

Parameter	***Delivered Capability***
Acquisition Axes	Vertical theta axis, Horizontal phi axis, Probe roll axis
Auxiliary Axes	Probe Z axis, AUT Z axis
Max. Scan Speed	30°/s
Theta Span	-180° < θ < +180°
Phi Span	0 < φ < 360°
Correction Capability	Encoder position feedback MTI thermal correction
Frequency Range	1 - 110 GHz
Position Accuracy	Theta: 0.008° peak error Phi: 0.007° peak error
Maximum AUT Size	Diameter: 2 m Weight: 100 kg
AUT Motion	Dual-axis rotation
AUT Mounting	Horizontal AUT mounted to phi stage
Z Axis Adjustment	25.4 cm probe translation 1.8 m AUT translation
Ideal Use	Characterizing low, medium and high gain antennas up to 110 GHz

To place the system in SNF mode, the operator simply commands the PNF scanner's probe to a fixed position (X, Y = 0, 0) to allow testing using the same near-field probe. Use of a floor-mounted AUT Z axis (visible in Figure 3) allows 1.8 m of adjustment of the probe-to-AUT separation to accommodate antennas of various sizes. This permits testing of antennas over a very wide bandwidth, roughly 1 GHz to 110 GHz. In addition to the AUT Z axis, a probe Z axis allows one to fine tune the probe-to-AUT separation for probe/AUT mutual coupling analysis.

2) Theta-over-Phi SNF

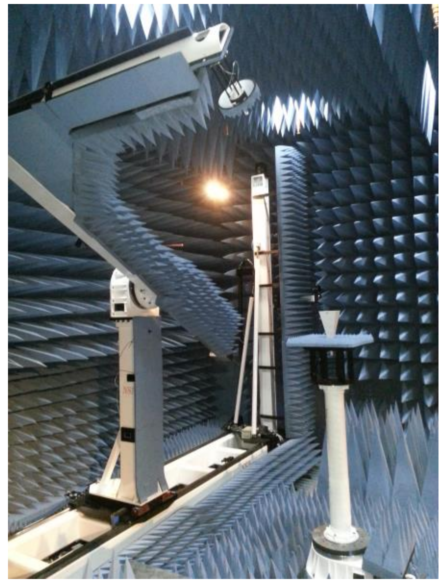

Figure 4. Theta-over-Phi Spherical Near-Field Scanner Measuring Ku-Band Standard Gain Horn Antenna - Planar Scanner Parked

A second SNF configuration is available in the chamber to allow testing of larger antennas, antennas with gravitational sensitivities and antennas operating at frequencies below 1 GHz. An image of this system in operation can be seen in Figure 4. To re-configure the range for theta-over-phi SNF testing, the following steps are followed:

1. Command the planar X-Y scanner into its safety parking area to avoid mechanical collisions. The planar scanner is seen parked in the safe area in Figure 4.
2. Move the swing arm support structure to the center of the guide rails.
3. Remove the phi-over-theta L-bracket to expose a large, 500 mm positioner.
4. Mount an antenna directly on the positioner or on a dielectric support column, as shown in Figure 4.

This configuration of near-field scanner allows data to be acquired over a partial sphere without requiring the AUT to be rotated on its side. This is an important requirement for certain antennas that deform when supported horizontally and subject to gravity. The probe travels along the theta axis in a partial circle with radius of roughly 2 m while the AUT rotates along the vertically oriented phi axis. A graphical representation of the data acquisition sphere is shown in Figure 5. This image also shows the planar scanner parked in its safe position.

In order to compensate for the effects of gravitational sag on the theta axis swing arm, on-the-fly droop correction has been implemented. With droop correction disabled, the worst-case droop is observed when the theta axis is commanded to ±

90°, as shown in Figure 6, where the actual position is in error by roughly 0.175°. After measuring and implementing the automatic theta axis droop correction, the observable error between commanded and actual position is on the order of 0.004° RMS.

TABLE IV. THETA-OVER-PHI SNF PERFORMANCE SPECIFICATIONS

Parameter	***Delivered Capability***
Acquisition Axes	Horizontal theta axis, Vertical phi axis, Probe roll axis
Max. Scan Speed	30°/s
Theta Span	-174.4° < θ < +174.4°
Phi Span	0 < φ < 360°
Frequency Range	0.2 - 50 GHz
Position Accuracy	Theta: 0.005° RMS Phi: 0.003° RMS
Correction Capability	Theta axis droop correction Encoder position feedback MTI thermal correction
Maximum AUT Size	Diameter: 2.5 m Weight: 2,500 kg
AUT Motion	Single-axis rotation
AUT Mounting	Vertical AUT mounted to phi stage
Ideal Use	Measuring large, gravitationally sensitive, or low frequency antennas

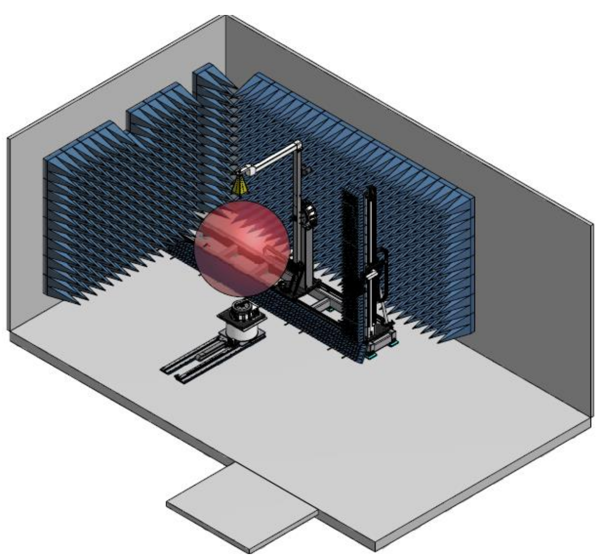

Figure 5. Theta-over-Phi SNF Scanner showing Data Acquisition Sphere Transcribed by Overhead Swing Arm and Rotating Phi Axis

C. Cylindrical Near-Field

Cylindrical near-field measurements can be performed on the University of Waterloo system by utilizing one linear axis (PNF Y axis) and two rotational axes (floor mounted theta axis, probe polarization axis). This configuration is well suited for testing fan beam base station antennas that are typically very directive in one plane and very broad in the orthogonal plane. These types of antennas can be characterized over a full 360° span in azimuth but far-field elevation data will be limited due to the finite length of the linear axis (4 m). With the phi-over-theta L-bracket shown in Figure 3 installed, one may perform planar, cylindrical and spherical near-field measurements without requiring any mechanical or RF system re-configuration. This is especially useful for educating students on the various near-field measurement types and their associated errors and limitations.

Figure 6. Commanded Theta Position Errors Before and After Compensation for the Theta-over-Phi SNF Configuration

D. Far-Field

When real-time, direct far-field measurements are required the operator must simply rotate the phi-over-theta positioner by 180° to be aligned to the chamber's far-field probe tower, as shown in Figure 1. An image of the probe tower with a large 0.2 – 2 GHz NSI-RF-RGP-200 broadband, dual-ridged horn antenna mounted is shown in Figure 7. With a maximum far-field range length of 7 m, this horn allows testing of antennas at 200 MHz with maximum dimensions larger than 2 m. Two additional dual-ridged horn antennas provide frequency coverage up to 40 GHz with a WR22 OEWG probe extending the far-field frequency range up to 50 GHz.

Figure 8 shows an estimated of the maximum antenna test size vs. frequency for the far-field system with a range length of 7 m. This shows that the far-field system is ideally suited for testing small, low gain antennas. This system is also very useful for training purposes, as direct far-field measurements are fundamentally important in the learning process of an antenna measurement engineer.

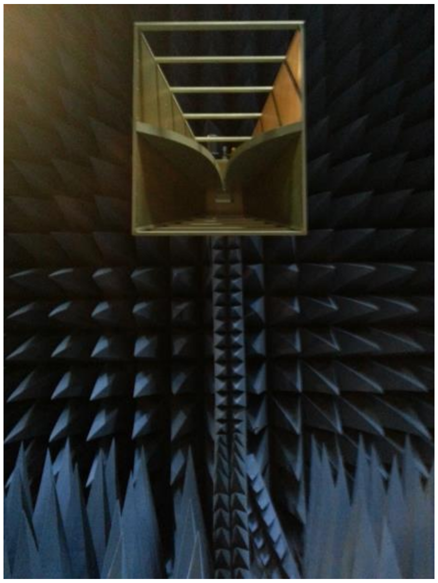

Figure 7. Far-Field Probe Tower with NSI-RF-RGP200 Broadband, Dual-Ridged Horn Mounted

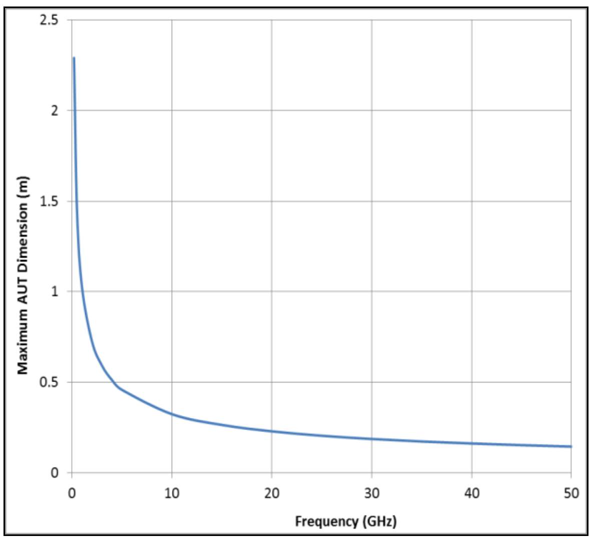

Figure 8. Maximum AUT Size vs. Test Frequency for Far-Field Subsystem

IV. RF SUB-SYSTEM

The RF sub-system for the University of Waterloo combination scanner is designed to support testing in all configurations from 0.2 - 110 GHz with a shared Agilent PNA-X VNA. However, as outlined in Section III, some configurations have practical limitations to their lower/upper frequencies due to AUT size, alignment requirements and chamber size constraints.

The system operates in the 0.2 – 50 GHz range in coax using a set of two broadband mixer modules designed and delivered by NSI. Measurements from 50 – 110 GHz are performed using two pairs of OML waveguide mixer modules (WR15, WR10). A distributed frequency converter located in the control room is responsible for down conversion. The system is capable of transmitting from either the AUT or the probe to support the characterization of non-reciprocal antennas.

V. INTERLOCK CONTROL SYSTEM

The combination planar, cylindrical, spherical near-field and far-field antenna test system described here employs a total of ten automated axes in order to allow dual-polarized acquisition in five different scanner configurations. Ensuring equipment, AUT and personnel safety in the vicinity of such a complex scanner posed a unique safety challenge. In order to address this issue NSI developed a safety interlock control system. The safety interlock control system's main functions are:

1. Provide safety interlocks and logic to prevent the scanners from mechanically interfering with one another.
2. Manage the process of safely switching from one scanner configuration to another.

The front panel of the interlock control unit (ICU), located on top of the equipment rack in the control room, is shown in Figure 9. The various LEDs on the front panel allow one to visually inspect the current status of the system. The panel provides the operator with status indicators of the scanner limits, current active acquisition mode, and potential interference risks. If all required conditions for a particular acquisition mode are not satisfied the system will enter a lock-out state until all issues are resolved.

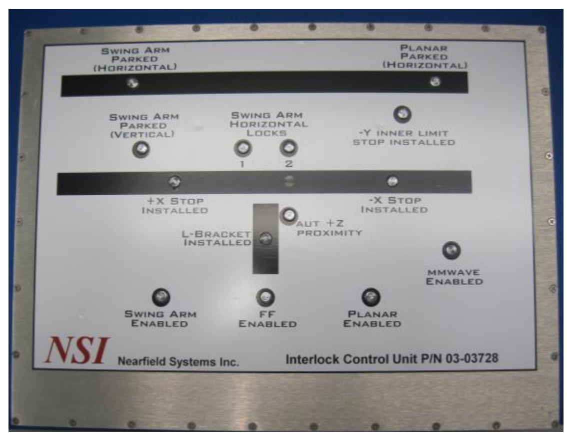

Figure 9. Front Panel Display of the Interlock Control Unit

An example of this would be if one attempted to perform a planar near-field measurement while the theta-over-phi swing arm is not safely secured in its parking area. When the swing arm is not safely parked and secured in place, an interlock switch remains in an open state. This logical false state disables motion of several axes to prevent interference. Inspecting the ICU front panel would indicate that the swing arm is not parked, instructing the operator to resolve the problem. Once the problem is resolved, the front panel will indicate that PNF testing is permitted. Two emergency stop-switches also allow the operator to manually enter a lock-out state. This is useful to ensure personnel safety while working in the chamber.

VI. CONCLUSIONS

A combination near-field and far-field antenna test system was recently installed at the University of Waterloo by Nearfield Systems Inc. This system allows planar, cylindrical, spherical and far-field measurements to be performed on antennas operating from 200 MHz to 110 GHz for a variety of antenna types. A shared RF sub-system allows testing in all configurations with minimal setup changes required. A safety interlock system reduces the risk of mechanical interference between the different scanner components.

VII. REFERENCES

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