Low Cost and High Accuracy Alignment Methods for Cylindrical and Spherical Near-field Measurement Systems

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ABSTRACT

Precise mechanical alignment of motion axes of both cylindrical and spherical near-field systems is critical to producing accurate data. Until recently the only way to align these types of systems was to employ traditional optical tooling (i.e. jig transits, theodolites). Alignment by these methods is difficult, time consuming, and requires specialized training. More recently, laser trackers have been used for this type of alignment. Unfortunately, these devices are expensive and demand an even higher level of operator training.

This paper describes the use of low cost alignment tools and techniques that have been developed by Nearfield Systems, Inc. (NSI) that greatly simplify the alignment process. Setup and alignment can be performed in a very short period of time by technicians that have been given minimal training. Suitable optical alignment procedures when followed by the use of electrical alignment techniques [7] yield sufficient alignment accuracy to permit testing up to Ku-band.

Keywords: antenna measurements, error analysis, spherical, cylindrical, alignment, laser, and optics.

1. Introduction

This paper describes the use of new techniques using low cost alignment tools to accurately align both spherical and cylindrical near-field measurement systems. The techniques described herein can be adapted to other types of near-field systems or far-field systems.

The motivation for this effort was a desire to establish a methodology that would allow for simplified alignment of the rotational axes of the scanner. An example of a Phi/Theta spherical measurement system is shown in Figure 1 while an alternate geometry using Theta/Phi is shown in Figure 2. Prior to conducting a measurement the operator must ensure the mechanical axes of the θ - and ϕ -rotators are aligned so they are both orthogonal and intersecting. The probe must also be aligned so that its rotational axis is coincident with the ϕ -axis. One must also ensure the rotator used to change the probe's polarization is also coincident with the ϕ -axis. The theta angle must also be set to zero when the phi axis is pointing directly at the probe. The methods to perform these alignments can either be optical, mechanical or electrical. All of these alignments are time consuming, and as the alignment tolerances become more demanding, the cost of the mechanical system and the alignment procedure increases.

When quantifying the effect of non-intersection errors on the AUT directivity, various studies have been undertaken to determine the axis intersection error tolerance [1, 2,3,4,5]. The error tolerance depends on factors such as:

- Operating frequency
- Required directivity accuracy
- Required sidelobe level accuracy
- Scanning method

Guidelines related to alignment tolerances can be chosen to meet technical requirements without excessive costs. Non-intersection errors of the θ - and ϕ axes to achieve a 0.2 dB amplitude error at the far-field peak depend highly on the type of scanning method used. Depending on the scanning method used, accurate results require alignment accuracy of 0.05 λ to 0.5 λ [6].

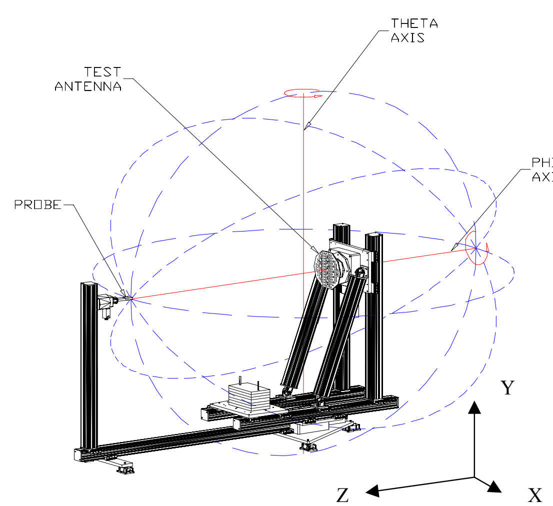

Figure 1 - Phi/Theta Spherical Scanning Configuration

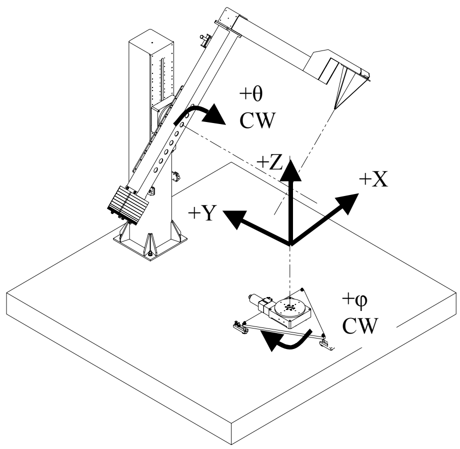

Figure 2 – Theta/Phi Configuration

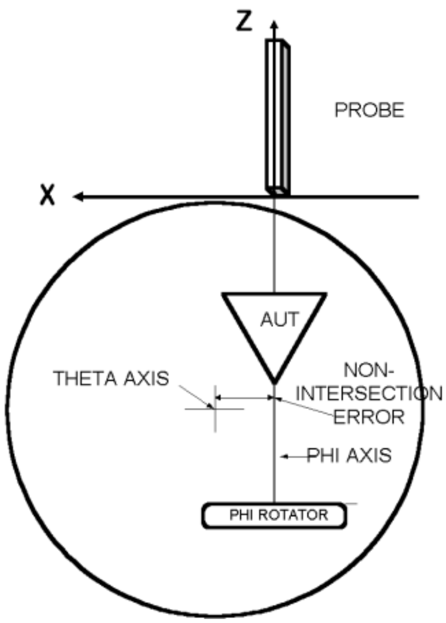

Figure 3 – Schematic of Non-Intersection Errors

2. Alignment Requirements

For spherical systems there are two steps in the alignment process. The first is the alignment of the theta, phi and probe axes on the scanner. The second is the alignment of the AUT on the Phi rotation axis. The scanner alignment must cover:

- Orthogonality and Intersection of Theta/Phi axes
- Coincidence of the probe and phi axes
- Orientation of the AUT axes with respect to the measurement coordinates.

The first step usually involves the alignment of the scanner axes without the AUT mounted. Once this has been achieved, the AUT is mounted to the Phi rotator and aligned.

3. Alignment Tools

Traditional methods of aligning spherical and cylindrical near-field systems involved the use of standard optical tooling including jig transits, theodolites, optical cubes, mirrors, etc. Within the past few years, high accuracy laser alignment tools, designed for the construction industry, have significantly fallen in price and improved in performance. NSI has evaluated a number of these tools for their applicability in aligning both spherical and cylindrical near-field systems. One product that has become available is a laser alignment tool that produces five orthogonal beams from a single laser source. The unit also has an auto-leveling feature that levels and plumbs all beams. The unit weighs 1.2 lbs. (525 grams), has dimensions of 5.5" (14cm) x 4.0" (10cm) x 2.5" (6.35cm) and has an advertised accuracy of +/- 1/4" (6mm) @ 100' (30m). The accuracy specification of the unit translates to 0.21mrad or 0.0119 deg. Performance of this unit has been confirmed by measuring the beam deviation using a laser tracker.

Figure 4 – Five Axis Laser Head

This laser head has a standard tripod mount accommodating a variety of stands and supports. In experimenting with various types of stands, we have found that a telescoping stand and an adjustable boom mount with a swivel head provides the highest flexibility and accommodates most of NSI system configurations. Figure 5 and Figure 6 show the telescoping boom stand with laser head mounted.

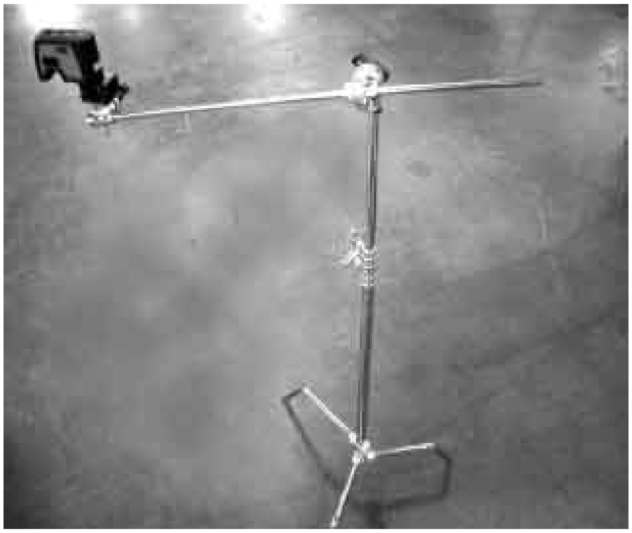

Figure 5 - Telescoping Boom Stand with Laser Head

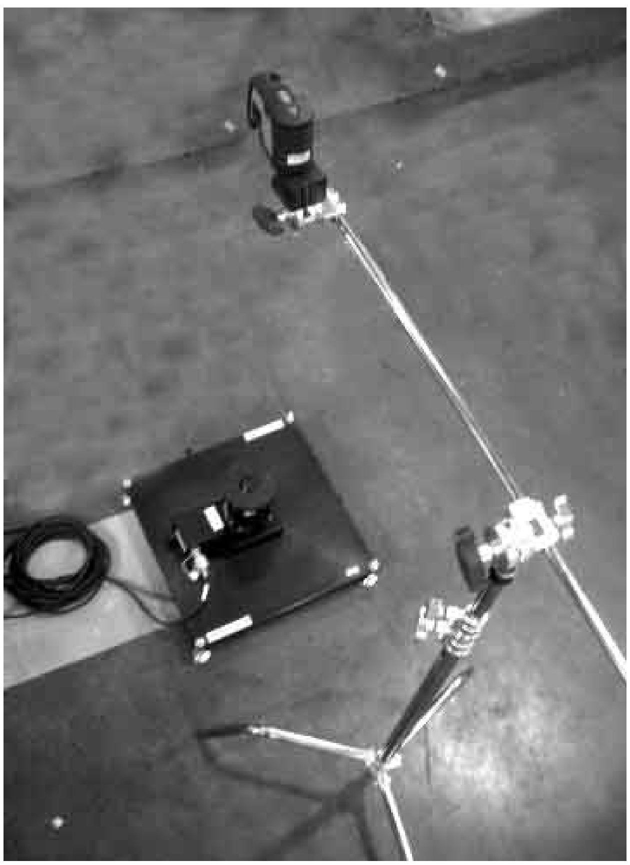

Figure 6 - Laser Head Positioned Over a Phi Rotation Axis

The tools and equipment that are required to align spherical and cylindrical systems using this laser-based approach are listed in Table 1 below.

Tool	Use
Five Axis Laser Unit	Provides orthogonal and level reference beams
Telescoping Stand with Adjustable Swivel Head	Mounting of laser unit
Precision Level	Used for leveling rotator stages
Axis Location Plate Tool	Finding the axis of rotation
Assorted Shim Stock	Used for fine mechanical adjustments
Masking Tape and Pen or Adhesive Optical Target	For temporarily marking the laser beam position
Spherical Alignment Procedure	Checklist for alignment

Table 1 - Common Alignment Tools

4. Alignment Procedure

The procedure used to align various systems depends on the type (theta/phi spherical, phi/theta spherical, cylindrical), size, and mechanical limitations of the structure. However, the basic alignment criteria remain the same for the system types:

Spherical –

The mechanical axes of the θ - and ϕ -rotators are aligned so they are both orthogonal and intersecting. The probe is also aligned so that its rotational axis is coincident with the ϕ -axis when $\theta = 0$ and the rotator used to change its polarization is also be coincident with the ϕ -axis.

Cylindrical –

The mechanical axes of the AUT azimuth rotator and the probe are aligned so that their rotational axes are intersecting and orthogonal over the entire vertical (Y axis) travel. The rotator used to change the probe polarization must also coincident with the probe axis.

In this paper we will focus on the spherical systems however cylindrical systems can be aligned using similar techniques. The requirements are more demanding for the spherical systems.

The following alignments must be completed for a Theta/Phi spherical scanner system shown in Figure 2 prior to taking RF measurements:

1) Making the θ-axis of rotation horizontal
2) Locating the theta axis of rotation using the laser locator
3) Making the φ-axis of rotation vertical

4) Locating the phi axis of rotation using the laser locator

5) Adjusting the phi axis to intersect the theta axis

6) Adjusting the probe and its rotation axis to be coincident with the phi axis

7) Setting $\theta = 0$ when the phi axis is directed towards the probe

A tool that facilitates the alignment of a rotator is a special alignment plate that has a small "target alignment hole" on the axis of rotation as shown in Figure 7 below. The plate may include alignment pins or have close bore through holes so that when the plate is attached to the rotator face, the alignment hole is at the center of the axis of rotation.

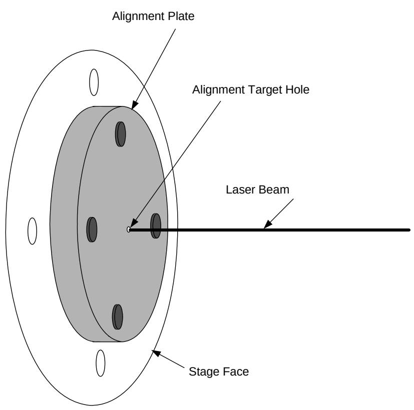

Figure 7 – Axis Alignment Using Alignment Plate with Target Hole

To center the probe axis, tape or a temporary target can be placed over the aperture to verify the center alignment of the probe antenna as shown in Figure 8.

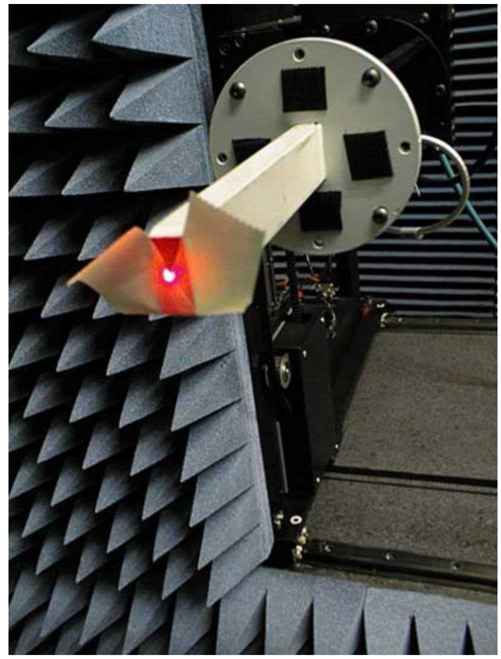

Figure 8 – Laser Image Striking the Probe Aperture Center Using Simple Tape Method

Another useful tool is a front surface mirror. This mirror is held against the face of the rotator as shown in Figure 9 and is used to reflect the laser beam back on itself. By observing the reflected beam's position relative to its source, the alignment of the rotator's axis is easily checked. A perfectly overlapping beam will confirm the axis of rotation is coincident with the laser beam.

Figure 9 – Using Front Surface Mirror to Determine Axis Alignment

Figure 10 illustrates the alignment of the probe roll stage using the laser alignment on a NSI-700S-30 Phi/Theta spherical scanner.

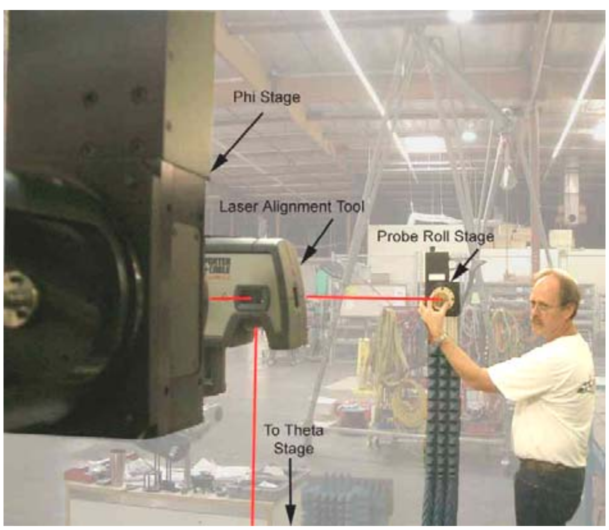

Figure 10 – Alignment of the Probe Roll Stage

For Theta/Phi (overhead swing arm) Spherical Systems where it is difficult to gain access to the face of the theta rotation stage a different method has been developed. To determine the axis of rotation a special tooling fixture is attached to the arm support structure. A precision spirit level as shown in Figure 11 is placed on the alignment tool oriented perpendicular to the rotator face. The position of the bubble is noted and the rotator is then moved 180 degrees. The position of the bubble is recorded again for the new position. The elevation tilt of the rotator is adjusted so the position of the bubble is equal to the original position. The alignment tool and level can also be used to check for backlash at $\theta = 0, \pm 90$ with the level at right angles to the rotation axis. Precise setting of $\theta = 0$ is accomplished by making the horizontal and vertical beams intersect the same point on the probe when rotated to ±90 and 0 respectively.

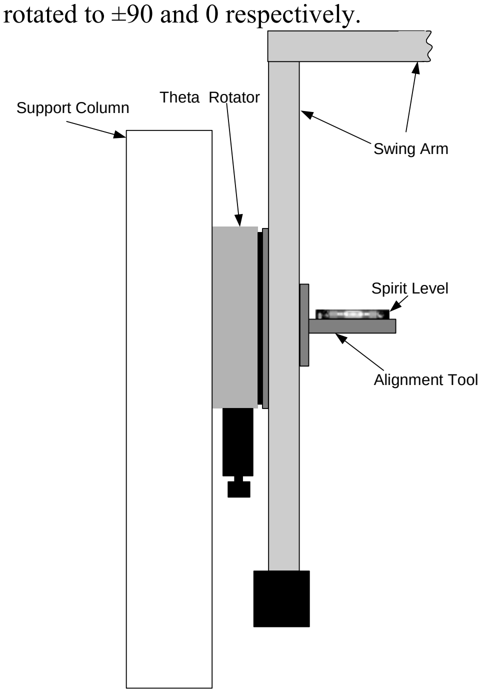

Figure 11 – Leveling the Theta Rotator Axis Using A Spirit Level and Alignment Tool – Theta/Phi Spherical System

5. Summary

The incorporation of low cost and accurate laser based alignment tools along with other simple tools can significantly reduce the complexity and time required to align spherical and cylindrical near-field scanning systems. Care must be taken to use procedures, tools and fixtures that are suited to the system that is being aligned. Suitable alignment procedures using new optical tools can significantly reduce the alignment time of spherical and cylindrical near-field scanners.

6. References

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7. ACKNOWLEDGMENT

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