PRECISION POSITIONER ALIGNMENT TECHNIQUES FOR SPHERICAL NEAR FIELD ANTENNA MEASUREMENTS USING LASER ALIGNMENT TOOLS

Jeffrey A. Fordham, John Proctor and Douglas Kremer

Microwave Instrumentation Technologies, LLC.
4500 River Green Parkway, Suite 200
Duluth, Georgia 30096

Abstract

The majority of precision spherical positioner alignment techniques used today are based on procedures that were developed in the 1970's around the use of precision levels and auto-collimation transits. Electrical alignment techniques based on the phase and amplitude of the antenna under test are also used, but place unwanted limitations on accurately characterizing an antenna's electrical/mechanical boresight relationship. Both of these techniques can be very time consuming. The electrical technique requires operator interpretations of data obtained from amplitude and phase measurements. The auto-collimation technique requires operator interpretations of optically viewed measurement data. These results are therefore typically operator dependent and the resulting error quantification can be inaccurate.

MI Technologies has recently developed a mechanical alignment technique for Spherical Near-Field antenna measurements using a tracking laser interferometer system. Once the laser system has been set-up and stabilized in the operational environment; the entire spherical near-field alignment may be completed in a few hours, as compared to the much more lengthy techniques used with level/transit or electrical techniques. This technique also simplifies the quantification of the errors due to the inaccuracy of the alignment.

This paper will discuss the effect of the alignment error on results obtained from spherical near-field measurements, and the procedures MI Technologies developed using a tracking laser interferometer system to obtain the precision alignment needed for a spherical near-field measurement.

Key Words: Alignment, Measurement Errors, Spherical Near Field

1. Introduction:

Tracking laser interferometers have been employed for a number of years for high accuracy machine tool calibration and control, large mold and die measurements, and large structural alignments. Recently MI-Technologies has developed a procedure that utilizes a tracking laser interferometer to aid in high accuracy alignment of Spherical Near-Field Systems.

The laser system works by tracking the movements of a spherically mounted retroreflector (SMR) mounted to some object which is under motion. The laser system includes an interferometer to measure radial distance from the laser and encoders on two orthogonal axes to measure translation.

By tracking a SMR mounted to a positioner turntable, highly accurate characterization of the center of rotation and the normal to the best-fit plane defined by the rotation of the turntable can be accomplished. These two characterizations are then used to adjust the AUT and probe positioners to remove the spherical near-field error terms.

After performing the following alignment procedure, the resultant mechanical alignment of the system is suitable for very accurate antenna boresight measurements as well as high frequency characterization of antennas.

2. Spherical Alignment Error Definitions

Although the definition of error terms has been published several times[1,2] they are included here for completeness and in the order in which they are easily adjusted using the proposed technique. Figure 1 illustrates the geometry.

1. *Non-Orthogonality of the theta and phi axes*: The theta axis is defined as the axis of rotation defined

by the rotation of the lower of the two AUT rotators. The phi axis is defined as the axis of rotation defined by the rotation of the upper of the two AUT rotators. Non-Orthogonality error is defined by the failure of these two axes to be perfectly 90 degrees apart.

2. *Non-Intersection of the theta and phi axes*: The intersection of the theta and phi axis is defined as the origin (O) of the spherical near-field coordinate system. Non-intersection error is defined as any translation error of the phi axis that causes the two axes to not intersect.
3. *Chi (or Probe) axis not parallel to the Z-axis*: This error is defined by the angle between the Chi axis and the Z-axis of the range coordinate system. In spherical near-field measurements, the probe axis must point directly at the coordinate system origin and lie on the Z-axis.
4. *Theta-Zero Error*: Defined as the angular error between the Chi axis of the probe and the Phi axis caused by rotation about the theta axis.
5. *Probe Y-zero error*: Defined as translation of the probe along the Y-axis.
6. *Probe X-zero error*: Defined as translation of the probe along the X-axis.

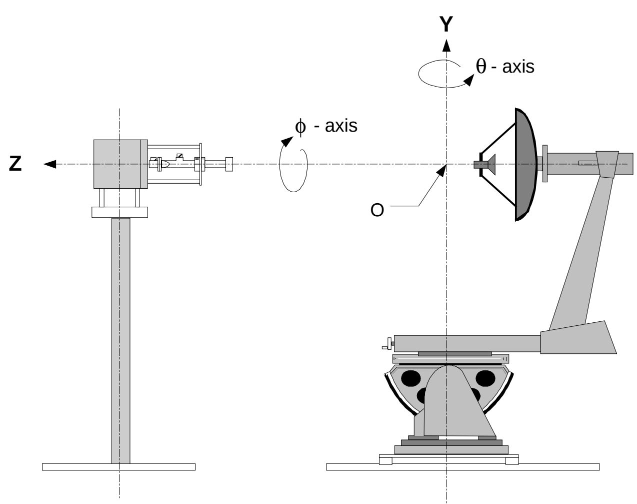

Figure 1: Spherical Near-Field Geometry Definition

3. Alignment Technique

1. Level the lower turntable using a precision master level and shims. Measure level between the mounting feet of the positioner as the turntable is rotated through its travel and adjust the shims under the positioner base as appropriate. Alignment of the theta axis to gravity can typically be achieved to within 0.0005 degrees using this method. Alternatively, the positioner can be leveled to gravity using the lasers internal level sensor, and measuring the height of a point on the perimeter of the turntable as it rotates through its travel range.
2. Measure a circle of points by rotation of the lower turntable. Determine a best-fit plane from this measurement. Establish the normal to this plane as the coordinate system primary axis and define it as the Y-axis. Since the lower turntable was leveled to gravity in step 1 by rotation of the lower turntable, the Y-axis of the laser coordinate system is now aligned parallel to gravity.
3. Measure a circle of points by rotation of the upper turntable. Determine a best-fit plane from this measurement. The normal to this plane defines the Phi-axis and is used for the laser coordinate system's secondary axis. The vector that lies in the plane defined by the primary and secondary axes and is normal to the primary axis is defined as the Z-axis. The X-axis is defined by the right hand rule. Note the laser system's axes are orthogonal and intersect even though the measured axes do not.
4. Adjust the tilt of the upper turntable support so that the phi-axis and the Y-axis are orthogonal.
5. Adjust the translation of the upper turntable support such that the measured Phi-axis intersects with the Y-axis (theta-axis). At this point the theta axis is aligned to gravity, the phi axis is aligned orthogonal to the theta axis (error 1 above) and the intersection error of the theta and phi axis has been removed (error 2 above).
6. Measure a circle of points by rotation of the probe rotator. Determine a best-fit plane from this measurement. The normal to this plane through the center of the best-fit circle is the Chi-axis (probe axis).
7. Determine the angles between the Chi-axis and the Z-axis projected into the YZ plane and into the XZ plane.
8. Adjust the probe mount tilt to remove the projected angle in the YZ plane.
9. Adjust the rotation of the lower AUT positioner turntable and/or the rotation of the probe tower to remove the projected angle in the XZ plane. Set the offset of the lower AUT rotator such that the current position is defined as zero.

10. At this point the Chi-axis is parallel to the Z-Axis (error 3 above) and Theta-zero error (error 4 above) have been removed from the system.
11. Re-measure the circle of points defining the Z-axis. Re-measure the circle of points defining the Chi axis.
12. Determine the offset in the XY plane of these two axes and adjust the probe translation in X and Y to bring the Z-axis and Chi-Axis coincident.
13. Error numbers 5 and 6, Y-zero and X-zero, have been removed from the system and the spherical near-field measurement system is now aligned.

4. Accuracy Discussion

The tracking laser interferometer system measures position by determining the location of the spherical mounted retroreflector (SMR) (a corner cube mirror mounted such the apparent reflection point is at the center of a highly accurate sphere). It determines the location of the SMR by counting the wavelengths of light as the distance between the SMR and laser changes, and by measuring encoders in the azimuth axis and elevation axis laser positioner as the SMR moves relative to the location of the laser.

The accuracy of the interferometer that is counting the wavelengths of light is 0.8 micrometers/meter from the laser. For a typical measurement distance of 5 meters this translates to a distance uncertainty of 4 micrometers. The encoder accuracy for the azimuth and elevation encoders results in a 5-micrometer/meter uncertainty. In order to minimize position measurement error of the laser a careful choice of laser position is chosen to minimize the rotation angle traveled by the azimuth axis to about +/- 30 degrees and travel of the elevation axis to about +/- 10 degrees. For these typical moves the uncertainty in a single measurement of position as the SMR moves through the full system geometry is 30 micrometers.

4.1 Uncertainty in determining the center of rotation of an axis

During the rotation of a given turntable the angle traveled by the azimuth and elevation axis of the laser axis is only about +/- 5 degrees and the total translational travel of the SMR is about 100 cm for a large turntable and as small as 20 cm for a smaller turntable. The maximum relative position error for these measurements is only 6.5 micrometers. Furthermore, when we measure a circle of points to define a plane, we measure about 50 points. The positional error in the center of rotation of this circle of points can be taken as proportional to the RMS error of the positional error in the individual points since the error in the position measurement of a set of points can be assumed to be gaussian in nature. For a set of 50 points on a 50 cm radius the uncertainty in the measured position of the center of rotation would be 2.2 micrometers from the true best-fit position.

4.2 Uncertainty in determining the normal to the face of an axis

In determining the normal axis to a plane of rotation, a circular feature is derived by measuring points as the SMR is moved through a full range of rotation then calculating the best-fit circle to this set of points. By considering the maximum error in the measurement of any single point it is possible to put an upper bound on the angular error between the normal to the plane of the derived circle and the true axis of rotation. This upper bound is calculated as: max angular error = arctan (max measurement error/radius of rotation). For a turntable with a radius of 50 cm. measured at a distance of 5 m. from the laser this approach gives an upper bound of 2.7 arc-seconds.

4.3 Residual Uncertainty in the SNF Error Terms

Based upon the uncertainty estimates in determining angular directions and position of centers of rotation, uncertainty estimates for the error terms in spherical near-field alignments using this laser interferometer technique are shown in the following table.

Error Term	Residual Uncertainty
Non-Orthogonality of the Theta and Phi Axis	5.4 arc-seconds
Non-Intersection of the theta and phi axis	17.5 micrometers
Chi axis not parallel to the Z-axis	5.4 arc-seconds
Theta-Zero Error	5.4 arc-seconds
Probe Y-zero error	31 micrometers
Probe X-zero error	31 micrometers

Table 1: Residual Uncertainty in the alignment of a Spherical Near-Field system using a Tracking Laser Interferometer.

5. Summary

The use of a laser interferometer at MI-Technologies has been shown to be extremely effective and highly accurate at assisting in the alignment of spherical near-field systems. The extreme accuracy achievable in the alignment of spherical near-field systems using this technique allows higher frequency antennas to be tested to greater degrees of confidence. Since the alignment is a high accuracy mechanical alignment, antenna boresight errors can be characterized with a higher degree of certainty than optical or electrical alignment techniques.

Furthermore since this technique can be used to align the turntable of the AUT positioner axis as well as an antenna mounted on the AUT axis, the system can be used for highly accurate measurements of an antenna when the positioner is under full load as well as alignment of the basic system to accommodate multiple antennas.

References

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