USING A TRACKING LASER INTERFEROMETER TO CHARACTERIZE THE PLANARITY OF A PLANAR NEAR-FIELD SCANNER

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ABSTRACT

This paper describes the experience of using a tracking laser interferometer to align and characterize the planarity of a planar near-field scanner. Last year, The Aerospace Corporation moved their planar near-field antenna range into a new larger room with improved environmental controls. After this move, the near-field scanner required careful alignment and characterization. The quality of the scanner is judged by how accurately the probe scans over a planar surface. The initial effort to align the scanner used a large granite block as a planarity reference surface and cumbersome mechanical probe measurements. However, a tracking laser interferometer was used for the final alignment and characterization.

The laser interferometer was included as part of an alignment service purchased from MI Technologies. The tracking laser interferometer emits a laser beam to a mirrored target called an SMR (Spherically Mounted Retroreflector). Encoders in the tracker measure the horizontal and vertical angles while the laser interferometer measures the distance. From these measurements, the three-dimensional SMR location is determined. The laser has the ability to very accurately (within about 0.001 inch) measure the location of the scanning near-field probe.

This paper includes a description of the mechanical alignment of the scanner, the tracking laser interferometer measurements, and the final planarity characterization.

Keywords: Antenna Measurements, Near-field Scanners, Planar Near-field, Range Evaluation, Alignment

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1.0 Introduction

After the planar near-field scanner at The Aerospace Corporation was relocated to a new facility, it required careful alignment and characterization. All of the initial alignments were performed using cumbersome mechanical reference measurements including the use of a large granite block. The large granite block has a smooth planar surface with a much smaller planarity tolerance than the near-field scanner. These methods were adequate but quite inefficient. In addition, the granite block did not allow the planarity of the full scan plane to be measured all at once. Furthermore, the near-field scanner moves at a much slower velocity during the granite block measurements compared to the normal operational velocity. To overcome these difficulties, The Aerospace Corporation, hired MI Technologies to align and characterize the planar scanner in less than a week using the tracking laser interferometer. The tracking laser requires some care in calibration, but is dramatically more efficient compared to the use of mechanical references such as the granite block [1]-[3]. The final characterization demonstrates that additional measures will need to be taken in order to reach the ultimate goal of performing accurate near-field antenna measurements up to 50 GHz.

2.0 The Planar Near-Field Scanner

At The Aerospace Corporation in the 1980s, a planar near-field scanner was constructed for the purpose of making antenna radiation pattern measurements. Although the theory of planar near-field antenna measurements was well established at this time, the availability of turnkey antenna near-field ranges was limited. So, the scanner was constructed from commercially available raw materials and components. The scanner moves a probe over a vertical planar surface in a rectangular coordinate system. The scanner consists of: (a) a horizontal steel base plate mounted onto the floor, (b) a horizontal set of rails mounted onto the steel plate, (c) a vertical aluminum I-beam mounted onto a carriage on the horizontal set of rails, (d) a vertical set of rails, and (e) a probe carriage. A photo of the scanner is shown in Figure 1. The probe typically moves at a velocity of 25.4 cm/s during an antenna measurement. The horizontal travel of the scanner is 106 in (2.7 m) and the vertical travel of the scanner is 82 in (2.1 m). Near-field measurements on this range have been performed up to 20 GHz, but work is in progress to upgrade the range to operate up to 50 GHz, including the use of remote mixers.

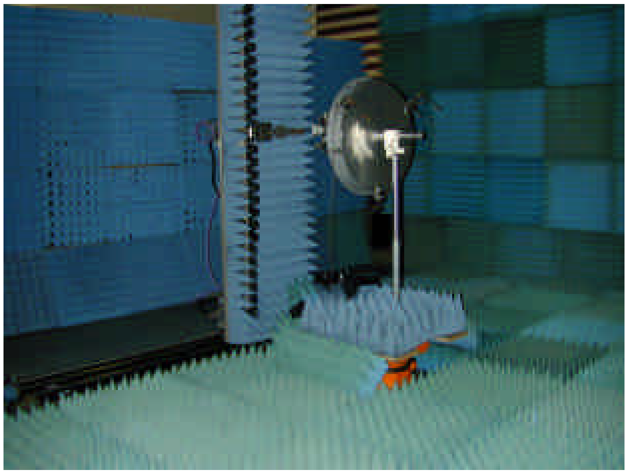

Figure 1: Photograph of The Near-Field Range.

In 2001, the planar near-field range was relocated into a larger facility that has better environmental controls, such as temperature and humidity. The near-field scanner required accurate alignment after it was relocated into the new facility. The rule-of-thumb used to establish an alignment goal for the planar near-field probe position accuracy is an RMS less than one fiftieth of a wavelength [4]. Since the objective for this facility is to perform measurements up to 50 GHz, the goal for the probe position error (measured from a perfect plane) is less than 0.005 inch. The first step in the alignment process is to make the base plate perfectly level, as shown in Figure 2.

Figure 2: Carlos Turano is working on the first step of the scanner alignment by making the base plate level.

3.0 Granite Reference Surface Measurements

For the next step in the alignment of the scanner, mechanical probe measurements were performed on a large granite block used as a planar reference surface. These mechanical measurements were cumbersome due to the large weight of the granite block (see Figure 3 for a picture of this type of measurement). The granite block measurements also had the limitation that they were only performed along one linear dimension (either vertical or horizontal). In addition, at each sample point in the scan plane, the probe stays at a fixed location while the distance to the granite block is measured.

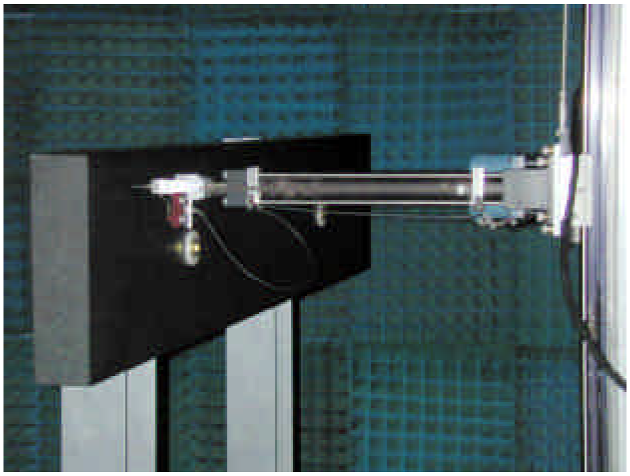

Figure 3: Photograph of Granite Reference Surface Measurement.

The granite block worked well for the initial alignment. However, the characterization of the entire scan plane when the probe is moving at full velocity was desired. To solve this issue, an alignment service was purchased from MI Technologies that includes the use of a tracking laser interferometer.

4.0 The Tracking Laser Interferometer

The tracking laser interferometer that was used by MI Technologies is the SMX Tracker 4000 [5] as seen in Figures 4 and 5. This laser emits a red helium-neon laser beam that is reflected from a target. A typical target is a spherically mounted retroreflector (SMR), as shown in Figure 6, that is a hollow corner cube mirror precisely mounted within a 38.1 mm tooling ball [5]. The SMR will reflect a laser beam, directly back to the source, over a range of incident angles up to ±20°. The tracking laser determines the coordinates of the target by measuring two angles and a radial distance. The angles are obtained from encoders on the elevation and azimuth axes. The radial distance is measured using a fringe counting interferometer.

The tracking laser is effectively recalibrated at the start of each measurement task by an on-site calibration process. The tracking laser device has a self calibration, but in addition, measurements are taken at fixed reference locations through the range to locate the near-field scanner in a global range coordinate system.

Figure 4: The SMX Model 4000 Tracking Laser Interferometer and John Proctor from MI Technologies.

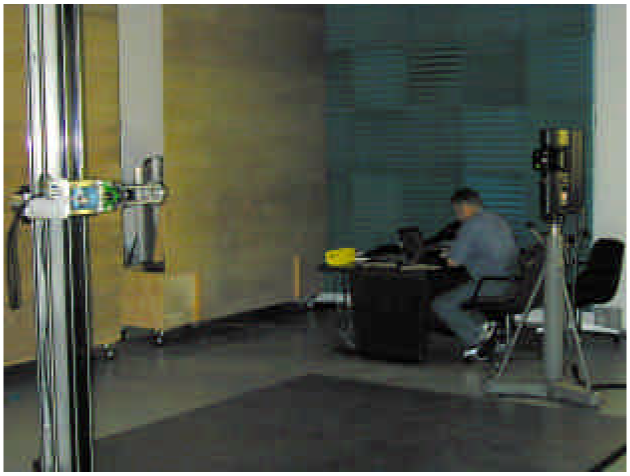

Figure 5: The Tracking Laser Interferometer, on the right side of photo, is located about 20 feet in front of the vertical planar near-field scanner.

A cut through the two dimensional grid of data obtained from the laser tracker can now be compared to the preliminary data from the granite block measurements, as shown in Figure 7. The curve for the granite block measurement is the average result from a series of 40 independent measurements. The agreement between the granite block measurement and the tracking laser is very good; within about 0.002 inch. The tracking laser measurement demonstrates that the probe has high frequency deviations as a function of the horizontal axis dimension (X). The granite block data does not show the high frequency deviations because a large series of stationary independent measurements (40 used here) is required to reduce purely random variations in the measurement. The tracking laser measurement is performed in real-time with the probe moving at the same velocity that is used during antenna measurements.

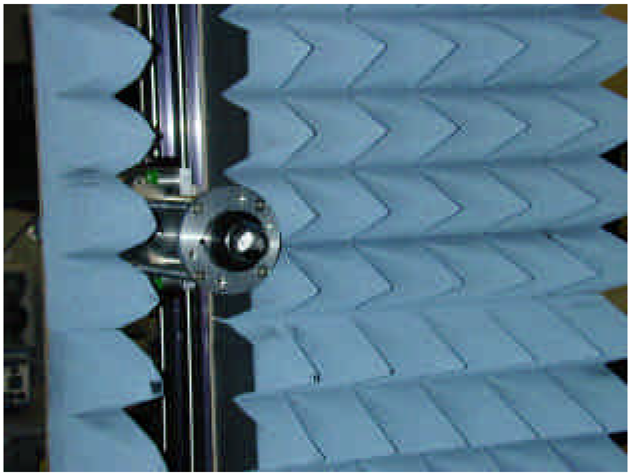

Figure 6: Photograph of the spherically mounted retroreflector on the probe carriage.

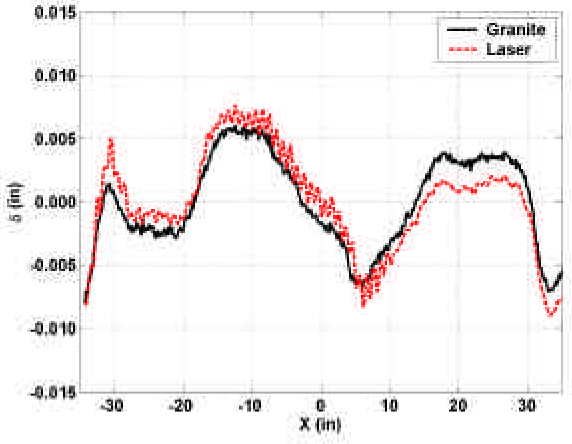

Figure 7: Probe position error with comparison of granite block measurement and laser measurement.

5.0 Alignment of The Planar Scanner

The alignment of the planar scanner proceeded in two steps. The first step was to align the steel horizontal base plate by adjusting the anchor bolts holding the steel plate onto the floor. Figure 8 shows the probe position error, with an RMS of 0.013 inch and a peak-to-peak variation of 0.058 inch, that was initially measured with the tracking laser before any adjustments were made. The probe position error is calculated from the probe position data by computing the position relative to a best-fit planar surface. Planarity data was collected on a 1 inch by 0.5 inch grid with the probe carriage moving at 10 in/sec. The ability to quickly generate graphic depictions of planarity error facilitates the determination of mechanical error sources.

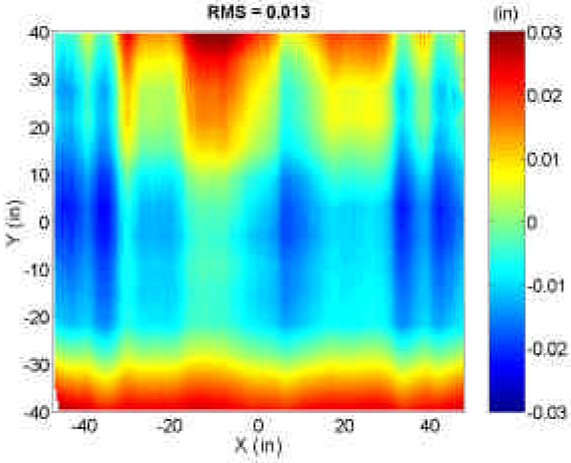

Figure 8: Initial scanner probe position errors with RMS = 0.013" (File: 010816 1342).

The steel base plate was carefully leveled before the scanner was assembled, so the later adjustments made on the base plate provided only a minor improvement, as seen in Figure 9, where the RMS is 0.012 inch and the peak-to-peak variation is 0.057 inch. The wave nature of the position error, as a function of "X" is caused by the two horizontal rails at the base of the scanner being slightly out of alignment. This error was reduced, as seen in Figure 9 compared to Figure 8. Also, notice in Figures 8 and 9 that there is a positive position error (shown by the red color) on the top and bottom of the scan plane. This type of error is caused by a curvature in the vertical aluminum I-beam. To correct this error, a steel square beam was bolted onto the I-beam to straighten out the vertical beam. From the result in Figure 10, it can be seen that this error was reduced. Figure 10 shows the final characterization of the planarity of the scanner with an RMS of 0.009 inch and a peak-to-peak variation of 0.061 inch.

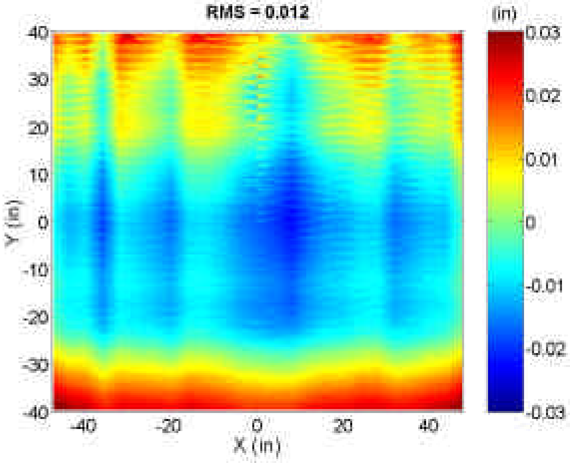

Figure 9: Scanner probe position error after alignment of base plate with RMS = 0.012" (File: 010817 1100).

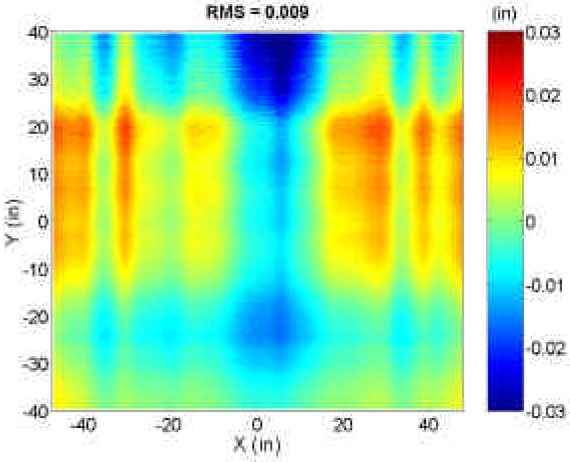

Figure 10: Final scanner probe position error after alignment of vertical I-beam with RMS = 0.009" (File: 010817 1850).

6.0 Conclusion

The Aerospace Corporation has successfully relocated a planar near-field scanner into a new facility. The initial alignment of the scanner, using cumbersome mechanical methods including the use of a large granite block, achieved a planarity with an RMS of 0.013 inch and a peak-to-peak variation of 0.058 inch over a 96 by 80 inch scan area. The use of a tracking laser interferometer to perform the final alignments and characterization achieved an RMS planarity of 0.009 inch and peak-to-peak variation of 0.061 inch, but proved to be significantly more efficient. The final alignments and characterization were completed in less than one work week.

The main benefits of using a tracking laser interferometer to align and characterize a planar near-field scanner are (a) the ability to accurately measure real-time probe position while alignment adjustments are made on the scanner, (b) the ability to accurately characterize the planarity of the scanner with the probe moving at full operational velocity, and (c) the ability to characterize the full scan plane in a single measurement event (single set-up).

The tracking laser interferometer can also be used to measure and map X- and Y- position accuracy and to measure static repeatability.

In order to obtain the goal of performing accurate antenna measurements up to 50 GHz with this near-field facility, further improvements are necessary.

The largest probe position deviations from a perfect planar surface are repeatable and deterministic. With the probe position characterization information, measurement accuracy can be improved by compensating for these known deviations by either (a) a real-time mechanical correction or (b) a software correction. Lorant Muth and also Ron Wittman, both from the National Institute of Standards and Technology, have formulated useful software probe position correction algorithms [6], [7].

7. REFERENCES

[1] Fordham, J., Proctor, J., Kremer, D., “Precision Positioner Alignment Techniques for Spherical Near Field Antenna Measurements Using Laser Alignment Tools,” AMTA 2000 Proceedings, Philadelphia, PA.

[2] Hess, D. W., Jones, J. R., Green, C., Melson, B. and Proctor, J., “Spherical Near-Field Antenna Measurements Improve Through Expanded Software Features,” Microwave System News, Vol. 15, No. 3, pp. 64-83, March 1985.

[3] Ondrey, T., Kremer, D., Garcia, V., Friedel, J., Keyser, R., “Completion of a Satellite Antenna Test and Repair Facility Relocation,” AMTA 1999 Proceedings, Monterey Bay, CA.

[4] *Antenna Parameter Measurement by Near-Field Techniques*, Short Course presented by The National Institute of Standards and Technology, April 1996.

[5] See the SMX web site for more information, http://www.smxcorp.com/, but note that SMX has recently become a division of FARO Technologies.

[6] Muth, L. A., “Probe-Position Error Correction in Planar Near Field Measurements at 60 GHz: Experimental Verification,” Journal of Research of the National Institute of Standards and Technology, Mar-Apr, 1992.

[7] Wittman, R. C., “Near-Field Antenna Measurements Using Nonideal Measurement Locations,” IEEE Trans. On Ant. and Prop., May 1998.

8. ACKNOWLEDGMENTS

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