

# ESTIMATING Z-POSITION ERRORS IN PLANAR NEAR-FIELD MEASUREMENTS FROM RF MEASUREMENTS

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## Abstract

Z-position errors are generally the largest contributor to the uncertainty in sidelobe levels that are measured on a planar near-field range. The position errors result from imperfections in the mechanical rails that guide the motion of the measurement probe and cause it to deviate from an ideal plane. The deviations  $\delta_z(x, y)$  can be measured with precise optical and/or laser alignment tools and this is generally done during installation and maintenance checks to verify the scanner alignment. If the measurements are made to a very small fraction of a wavelength in Z and at intervals in X and Y approximating one half wavelength, the sidelobe uncertainty can be estimated with high confidence and is usually very small. For Z-error maps with lower resolution the resulting error estimates are generally larger or have lower confidence.

This paper describes a method for estimating the Z-position error from a series of planar near-field measurements using the antenna under test. Measurements are made on one or more planes close to the antenna and on other planes a few wavelengths farther away. The Z-distance between the close and far planes should be as large as the probe transport will allow. The difference between the holograms calculated from the close and far measurements gives an estimate of the Z-position errors. This approach has the advantage of using the actual AUT and frequency of interest and does not require specialized measurement equipment.

**Keywords:** Antenna measurements; Error Correction; Planar near-field;

## 1.0 Introduction

The error in the on-axis gain and sidelobe can be estimated from the following equations<sup>1</sup>.

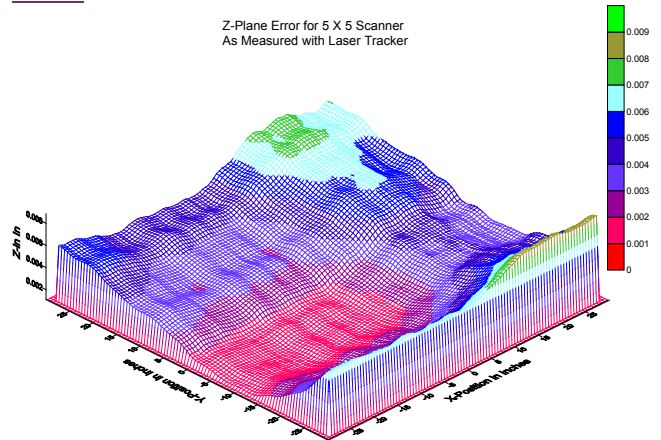
$$\Delta G_{dB}(\theta, \phi) \leq \frac{43}{\sqrt{\eta}} \left( \frac{\delta_z(rms)}{\lambda} \right)^2 \cos^2 \theta_B g(\theta, \phi) \quad (1)$$

[Main Beam]

$$\Delta P_{dB}(\theta, \phi) \leq \frac{13.5 \delta_z(\theta, \phi)}{\lambda} \cos \theta_B g(\theta, \phi) \quad (2)$$

[Sidelobes]

where  $G$  is the antenna gain,  $P$  the relative pattern,  $\lambda$  the wavelength,  $\eta$  the aperture efficiency, and  $\delta_z$  the position error.  $g(\theta, \phi)$  is the reciprocal of the sidelobe level in voltage not dB, for instance, for a  $-40$  dB sidelobe,  $g(\theta, \phi)$  is 100.



**Figure 1 Z-error map from laser tracker measurements.**

To estimate the gain error, only the RMS value of the Z-position error is required, but for the sidelobes we need the amplitude of periodic Z-errors. Errors that are periodic in X or Y will produce an error in a sidelobe with the magnitude given by Equation (2). Because of the factor  $g(\theta, \phi)$ , the error can be very large for low sidelobes.

The best way to determine the periodic error components for a given planar scanner is to use precision optical instruments such as laser straightness systems or laser trackers that will measure the Z-error over the complete scan area. The result of one measurement is shown in Figure 1 where a laser tracker was used to measure a small planar scanner. With this data, the periodic components can be determined and the error reliably estimated. This result can also be used to create an error correction grid that is used to move the probe in the Z-direction during measurements and automatically correct for the measured position error.

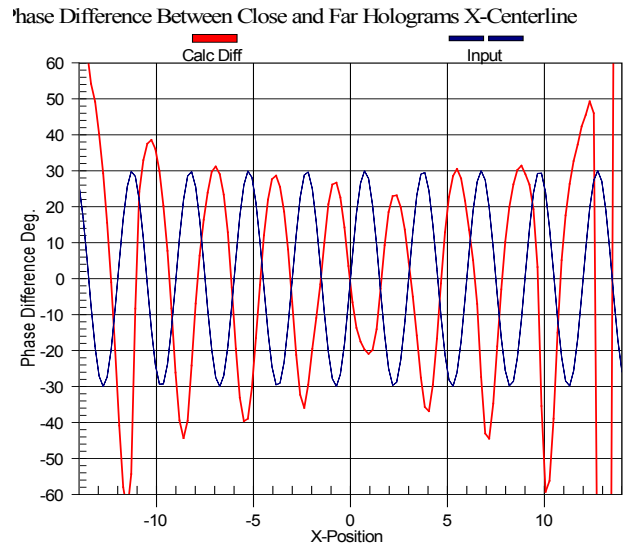
The period of the error components is as important as the magnitude of the error. Components with periods less than  $\lambda$  will produce sidelobes beyond real angles and will not cause errors in any real sidelobes. Periods greater than approximately  $L_x/2$  or  $L_y/2$  will affect the main beam region where Equation 1 will apply.  $L_x$  and  $L_y$  are the AUT dimensions. Any test that is developed should therefore focus on periodic error components with periods in the interval

$$\lambda \leq \tau \leq \frac{L}{2} \quad (3)$$

Tests have been developed for most of the terms in the 18 Term Error Analysis that can be performed on the Antenna Under Test (AUT) and the actual measurement system to estimate the magnitude of the individual error. In these tests, two or more measurements are compared and the difference in the far-field patterns provides an estimate of the error. Some part of the system is changed between measurements that will cause the individual error source to change in magnitude or sign. There has not been this type of test for the Z-position errors and so the measured position error data has been relied on. The measurements with the laser equipment are not always available and so the complete data similar to Figure 1 is not always available. Without the complete error map, the user may be forced to make large estimates of uncertainty for low sidelobe results. The following technique was developed to provide an alternative to the position mapping measurements when these are not available. It does not give the complete results that the mapping does, but it can be used to give more reasonable estimates of uncertainty when mapping data is not available or when the mapping data is done only at a low density as is common when using standard optical tooling equipment instead of a laser tracker.

## 2.0 Measurement and Calculations to Estimate Z-Position Errors

The proposed measurement technique uses planar near-field data taken on at least two planes separated by a distance D. The separation should be as large as possible while maintaining accurate AUT and probe alignment. The near-field data will be different on the two planes, but if there were no errors each data set should produce the same far-field pattern. Both measurements should also produce the same hologram of the aperture distribution for any plane up to touching of the antenna. If there are Z-position errors due to scanner mis-alignment, both data sets will have a nearly identical variation in phase that is proportional to the position error. This phase variation will be transformed differently from the two different distances and the result will be a difference in the computed holograms. The difference in the holograms should then be a measure of the phase error.

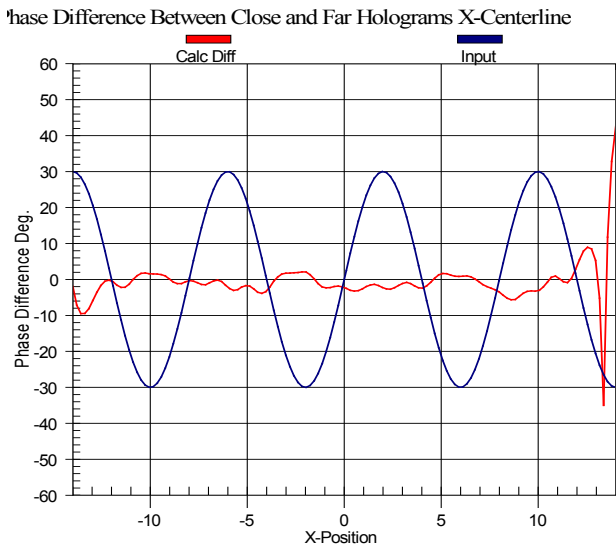


**Figure 2 Sample result of simulation for 30 degree phase error with a period of 3 inches.**

To test the idea, a simulation was used where ideal measured data on the two planes could be derived from a single measurement. The measured data was used to calculate synthetic data on two measurement planes that were separated by a distance D. The hologram calculation was used to produce the new data sets. A periodic phase error was then applied to each data set simulating a Z-position error. The peak magnitude and period of the phase error could be set to any desired value. The hologram calculation was again used on each of the data sets to calculate the phase distribution on a plane near the aperture of the antenna. Finally the difference in the phase of the two holograms was calculated and compared to the input phase error. One result of this simulation is shown in Figure 2. In this case, the magnitude of the input phase

error was 30 degrees and the period was 3 inches. The distance between the two simulated measurement planes was 10 inches.

The calculated difference in the hologram phase in this case is an accurate measurement of the magnitude of the input error. It does not reproduce the identical pattern of the input error and the results cannot be used to correct the scanner, but it does give a reliable estimate of the period and magnitude of the input error. The results can therefore be used with Equation (2) to estimate the angular location and magnitude of sidelobe errors.



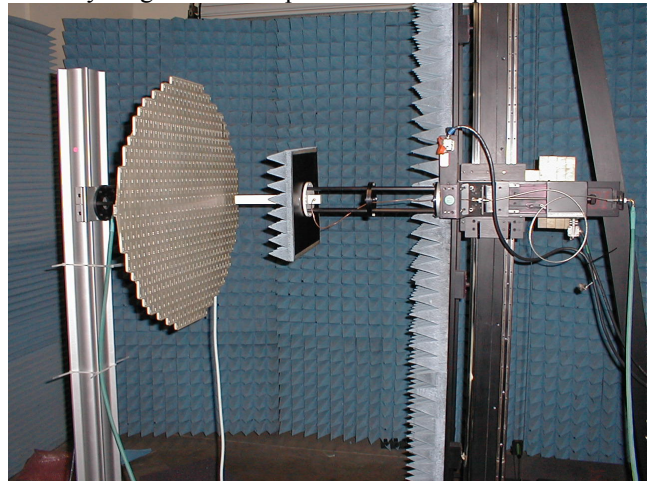
**Figure 3 Sample result of Z-error simulation where period was greater than measurement plane difference D.**

A series of simulations was performed for different error magnitudes, periods and measurement plane separation distances. The results of those simulations seemed to indicate that the technique could detect very small errors of less than a degree as long as the separation distance between measurement planes was greater than the period of the input error. Figure 3 shows an example where the separation distance was 5 inches and the period of the error was 8 inches. In this case the error is not correctly identified.

### 3.0 Measurement with Induced Z-Errors

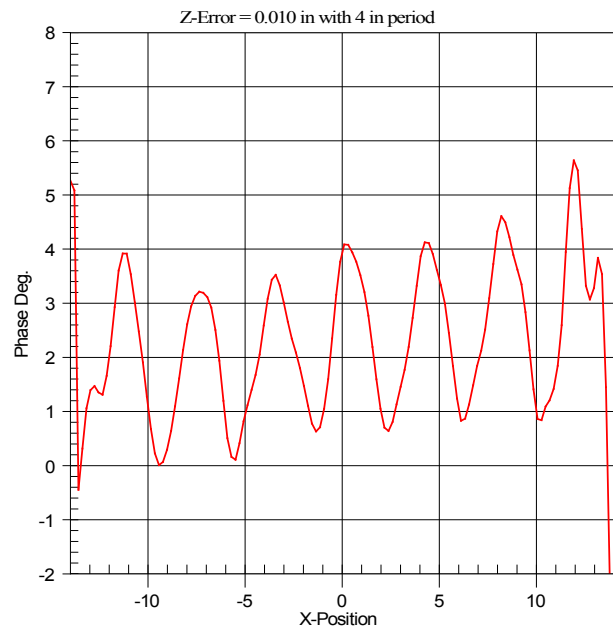
To further test the proposed technique, actual measurements were performed where a known Z-error could be introduced. The Z-error was introduced by creating a “correction grid” that was used by the computer software to automatically control the Z-position of the

probe. This correction grid is normally used to correct for measured Z-errors, but in this case it was used to induce a known Z-error. Periodic errors in both X and Y with arbitrary magnitudes and periods could be produced to test



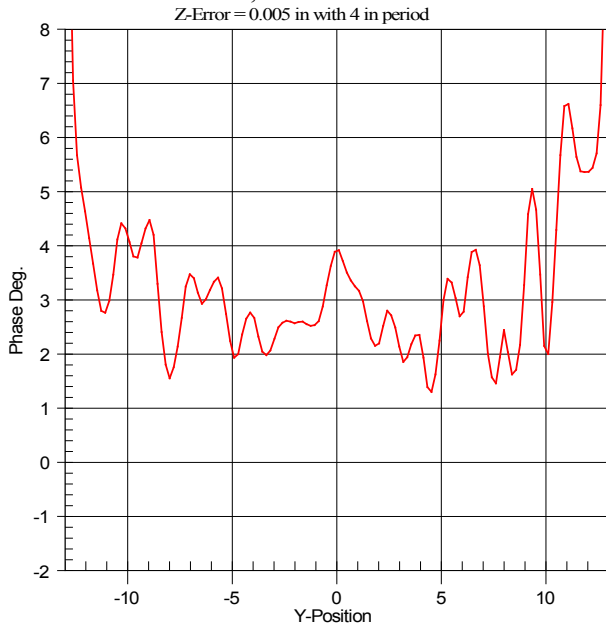
**Figure 4 Antenna used for measurements on planar near-field range.**

the proposed technique. Figure 4 shows the antenna that was used for these measurements. It was a slotted array operating at 9.3 GHz. The probe translation stage is also shown in the picture. This translation stage was computer controlled to induce the Z-position errors and was also used to move the probe to different measurement planes.



**Figure 5 X-direction hologram phase difference for 0.010 in (4.6 Deg.) magnitude Z-error.**

In the computer simulation described in the last section, two planes of data were generated. Since they were generated from the hologram calculation, they had identical effects due to multiple reflections and truncation. In the actual measured data, the measurements at the close



**Figure 6 Y-direction hologram phase difference for 0.005 in (2.3 Deg.) magnitude Z-error.**

distance will have a different level and character of multiple reflection error and this difference could affect the phase difference between the holograms. Unless the multiple reflection effect is reduced, we may not be able to distinguish between residual multiple reflection differences and Z-position error effects. To reduce multiple reflection effects, 3-5 measurements were taken at intervals of  $1/8$  at the close distance and at the same intervals at the far Z-distance. The hologram phase was computed for each individual data set and then the 3 or 5 measurements were averaged to reduce the effect of multiple reflections. The average at the close distance was then subtracted from the average at the far distance to give the final measure of the phase error due to Z-position errors.

A similar problem may exist due to differences in truncation effect at the near and far distances. This could possibly be handled by changing the scan length of the close distance data so the angle subtended by the scan plane was the same in both cases. This was not done in the current measurement but could be tried in future measurements to improve the results.

The results of one set of measurements is shown in Figures 5 and 6. For this measurement, the closest Z-distance was 3.9 in and the maximum Z-distance was 7.4 in. The error

grid for these measurements produced a Z-error with a magnitude of 0.010 in and a period of 4 inches in the X-direction and a magnitude of 0.005 in and a period of 4 inches in the Y-direction. The observed phase differences should have been 2.8 degrees in the X-direction and 1.4 degrees in the Y-direction and the results are consistent with these values. Since the Z-distance between the close and far planes was 3.5 inches, the 4 inch period is slightly larger than optimum, but the results are encouraging.

Other tests were performed with different types of induced errors and different separation distances between planes. These confirmed the basic conclusions from the ideal simulation that errors on the order of 1 degree in phase corresponding to a Z-error of 0.003 in can be detected. It also confirmed the relationship between the separation distance between the planes and the largest period that could be detected. Details of these tests will be shown in the presentation.

## 4.0 Conclusions

A measurement technique for estimating the magnitude and period of Z-position errors in planar near-field scanners has been developed and tested. While it has some limitations, primarily due to the maximum Z-travel for the probe translation stage, it can be useful when little or no precise, detailed Z-error map is available.

## 5.0 References

- <sup>1</sup> Newell, A. C., "Error analysis techniques for planar near-field measurements," *IEEE Transactions on Antennas and Propagation*, Vol. AP-36, pp. 755-768, June 1988.