THE EFFECT OF MEASUREMENT GEOMETRY ON ALIGNMENT ERRORS IN SPHERICAL NEAR-FIELD MEASUREMENTS

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Abstract

Papers were presented at the last two AMTA meetings reporting on the effect of rotator system alignment on the results of spherical near-field measurements. When quantifying the effect of non-intersection errors on the AUT directivity, these two papers presented very different results. One AMTA paper[1] and an earlier study at The Technical University of Denmark[2] found that the directivity error was extremely sensitive to non-intersection errors while the other AMTA paper[3] found a very small sensitivity. During the past year, scientists at the Technical University of Denmark, The National Institute of Standards and Technology, and Nearfield Systems Inc. have been working together to determine the reasons for these differences. It now appears that the major reason for the difference is due to the method used to acquire data on the sphere. Theta scans that pass through the pole, or equivalently, phi spans of 180 degrees, produce both plus and minus phase errors that tend to cancel in the on-axis direction. Theta scans that do not pass through the pole, or equivalently phi spans of 360 degrees, produce phase errors of the same sign over the sphere which are concentrated in the on-axis direction. Examples of measurements and recommendations for using this information in spherical measurements will be presented.

Keywords: Antenna Measurements, Near-field, Spherical, Error Analysis, Simulation

1. Introduction

The motivation for all three of the research efforts was a desire to establish alignment accuracy requirements for the spherical near-field measurement system. An example of a typical measurement system is shown in Figure 1. Previous to measurement, optical, mechanical or electrical measurements must be performed to align the mechanical axes of the θ- and ϕ-rotators so they are both orthogonal and intersecting. The probe must also be aligned so that its axis is coincident with the ϕ-axis and the rotator used to change its polarization is also coincident with the ϕ-axis. 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. The users of measurement systems need reliable guidelines so the alignment tolerances can be chosen to meet technical requirements without excessive costs. It is therefore important to resolve the apparent differences in the conclusions of these studies, since for instance to limit the error due to non-intersection of the θ- and ϕ axes to 0.2 dB, one result would require alignment accuracy of 0.05 λ, while the other allows alignment uncertainties of 0.5 λ.

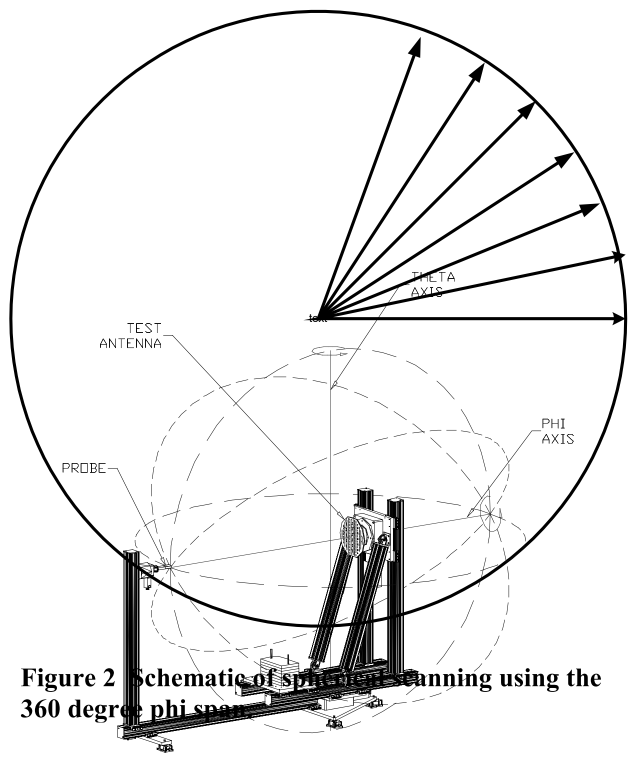

Figure 2 Schematic of spherical scanning using the 360 degree phi span.

Figure 1 Typical spherical near-field measurement rotator system.

To resolve these issues, researchers at Nearfield Systems

Inc. (NSI), The Technical University of Denmark (TUD), and the National Institute of Standards and Technology (NIST) have been cooperating during the past year. Differences in the measurements or data processing that could possibly account for the different results were first identified for further study. The differences that were identified were: 1- Different measurement systems and measurement equipment. 2- Different test antennas and probes. 3- Different computer software for processing the measured data. 4- Different scanning methods (this will be discussed in more detail). 5- Different alignment techniques.

It is unlikely that items 1, 2, and 5 could produce the large differences that were observed, and so initially the focus was on testing the two software programs. The NSI software uses the NIST spherical software package, while the TUD software was developed at their laboratory. While they are both based on the spherical near-field theory and use similar numerical analysis techniques that rely on the application of the FFT and matrix multiplication, they have been developed independently, and could produce different results when measurement errors are present. Measurement data was exchanged between TUD and NSI with the goal to determine if the data would produce the same result using the different software. Due to differences in data format and programming availability, this effort is still underway. But upon receiving the TUD data it became apparent that the different scanning methods could very likely explain the noted differences. The major effort was then focused on repeating the TUD measurements at the NSI facility and demonstrating that the different result was due to the measurement methods and not on the software. The remainder of this paper will therefore focus on the new measurements carried out at NSI using both measurement methods.

2. Description of Scanning Methods

In spherical near-field measurements, amplitude and phase data are measured at equally spaced points on the surface of a sphere that encloses the Antenna Under Test, AUT. For broad-beam antennas, or for complete patterns over the full sphere, measurements are required over the complete sphere. For fairly directive antennas, measurements may be performed over a portion of the sphere where the signal level is significant. The measurement region can be covered by scanning in ϕ and stepping in θ, referred to as ϕ scans, or by scanning in θ and stepping in ϕ, referred to as θ scans. For an accurately aligned rotator system and the fast

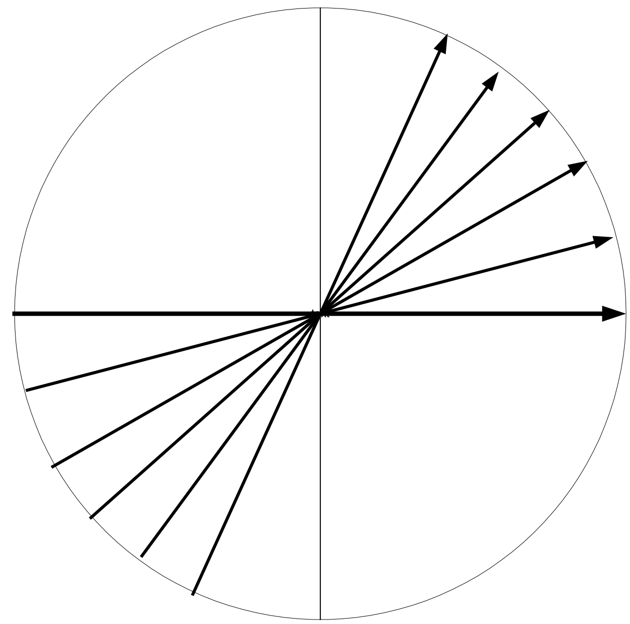

Figure 3 Schematic of 180 degree phi span scanning method.

modern receiver and measurement electronics, the two scanning options should produce equivalent results. The choice is generally based on convenience and desires to reduce measurement time. In addition to the scan and step options, the sphere can be covered by using either of two methods that involve different spans in θ and ϕ. These two methods are shown schematically in Figures 2 and 3 for the case where the forward hemisphere is measured using θ-scans, but the concept applies to any scan region including the full sphere and to either θ-scans or ϕ-scans. Only the first few scans are shown in each case.

Figure 2 illustrates the scanning approach that will be referred to as the 360 degree phi span method, since ϕ is varied between 0 and 360 degrees. In this approach, θ has only positive values and is measured from the pole outward and therefore the data points on opposite sides of the pole are not measured in a continuous scan. Using this approach, the θ and ϕ angles have the conventional spans for a spherical coordinate system, namely 180 degrees for θ and 360 degrees for ϕ. This is the scanning method that TUD uses for their measurements in both studies.

Figure 3 illustrates the alternative scanning approach referred to as the 180 degree phi span approach. In this approach, θ is measured continuously on both sides of the pole and has both positive and negative values. ϕ is varied between 0 and 180 degrees. Before processing the data obtained in this way, the phases of all measurements with negative θ locations are changed by 180 degrees to account for the different probe orientation on half of the sphere. This is the scanning method that was used for all of the previous NSI measurements.

If the measurement system is correctly aligned, both of these approaches should give equivalent results, and this will be demonstrated in the following measurements. If there are alignment errors, the effect on the measured data will depend on which scanning method is used, and the resulting effect on the far-field results will also be different.

3.0 Non-Intersection Errors

The effect of non-intersection errors on the AUT directivity arises because the non-intersection errors produce a systematic phase error on the measured data as shown in Figure 4. As the AUT is rotated about the θ-axis, the AUT moves in the z-direction due to the alignment error and the change in the z-position of the AUT is given by,

$$\Delta z = \Delta I \ \sin(\theta) \qquad \text{where } \Delta I = \text{non-intersection error} \tag{1}$$

When using the 180 degree phi span, the phase errors are positive over half of the hemisphere where θ is positive and negative over the other half where θ is negative as illustrated in Figure 5. The resulting effect on the far-field pattern in the on-axis direction is very small since the positive and negative errors tend to cancel out. The 360 phi span produces phase errors of the same sign over the full hemisphere as shown in Figure 5, and the resulting effect on the far-field on-axis is quite significant. Depending on the sign of the non-intersection error, the phase error can either increase or decrease the apparent gain or directivity.

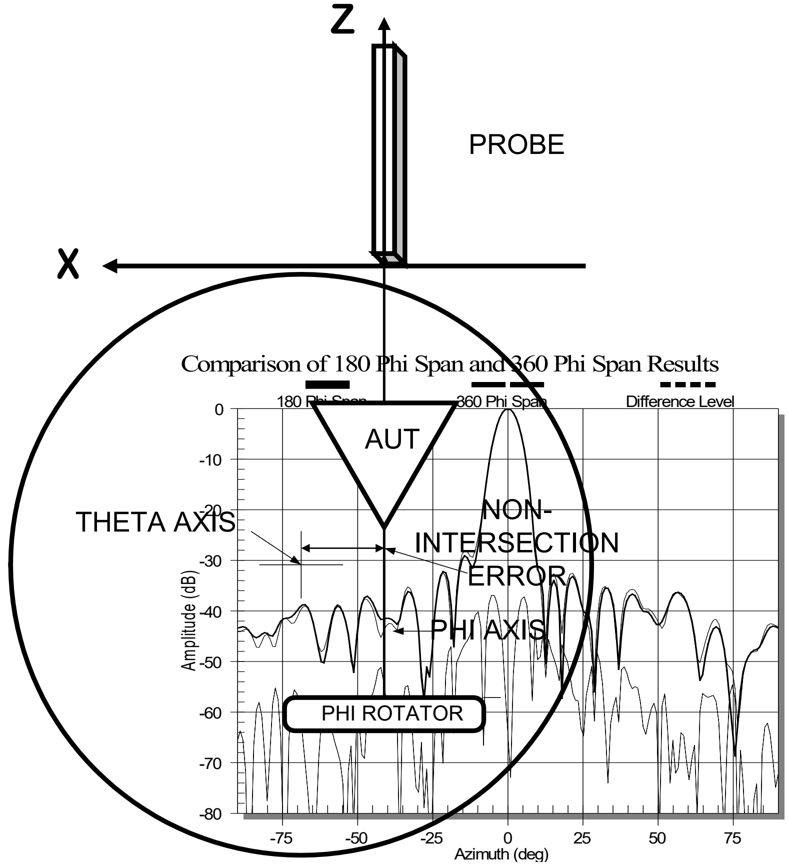

Figure 4 Schematic of non-intersection error.

80 phi span

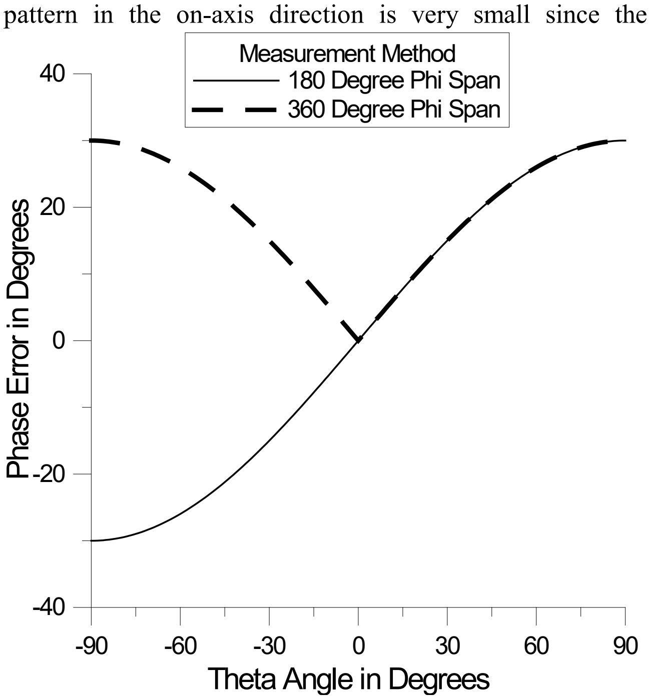

Figure 5 Phase error due to lambda/12 non-intersection error. Theta angles shown are for 180 degree phi span.

4.0 Measurement Program

To verify the conclusions of the previous section, a series of

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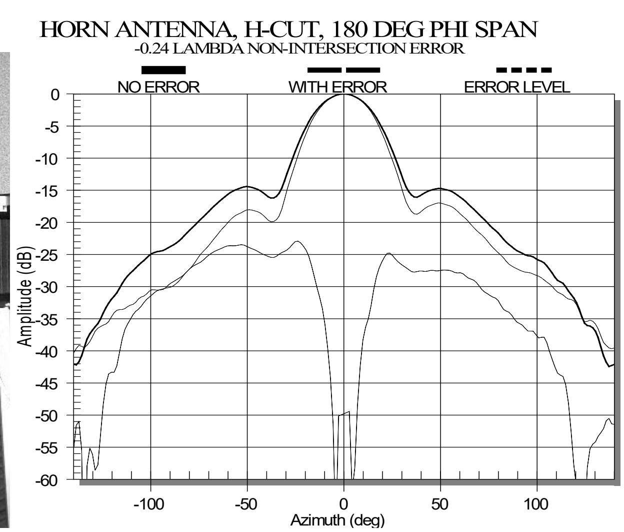

Figure 8 Example of the effect of non-intersection error for a 180 phi span measurement.

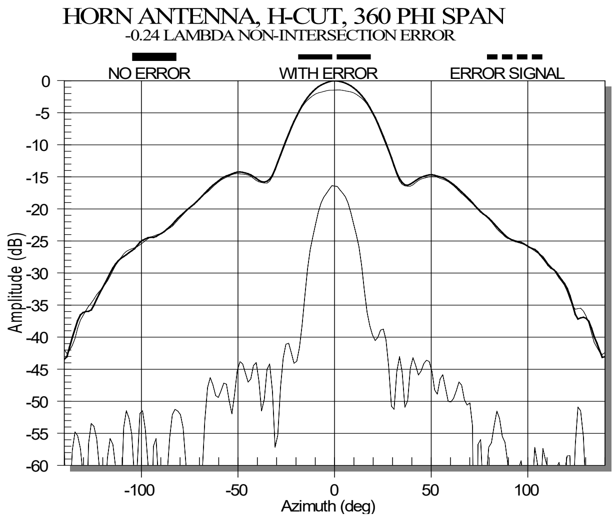

Figure 9 Example of the effect of non-intersection errors for 360 phi span measurements.

spherical near-field measurements were made at NSI . Two antennas were used, a small horn with a gain of 15 dB and the array shown in Figure 6 with a gain of 30 dB. The translation stage behind the phi rotator that was used to automatically induce non-intersection errors is visible in the picture. The measurement system was first aligned using a combination of mechanical and electrical tests. Spherical measurements were obtained for both antennas using both the 180 and 360 phi span methods. Non-intersection errors ranging from –0.4 to +0.4 λ were induced during the measurement and the far-field patterns for both main and cross component were obtained and compared to results without induced errors. Figure 7 shows a comparison of patterns without any errors. These were taken on the same day with no changes in the system between measurements. This illustrates that the two scanning methods produce the same results within the limits of the residual errors.

Figures 8 and 9 show similar plots for the case where the non-intersection alignment error was –0.24 λ. Both curves on a given plot are shown relative to the peak of the pattern without errors. These figures illustrate the general character of the results for all of the non-intersection error simulation. The effect of the non-intersection error for the 360 degree phi span measurements is localized near the peak of the main beam and results in either a decrease or increase in the gain and directivity depending on the sign of the error. The relative pattern beyond the peak of the main beam is effected very little. In contrast, the results of the 180 degree phi span measurements show very little effect near the peak of the main beam, but the relative pattern off the peak of the beam is changed considerably. Curves similar to these were produced for main and cross components, H-cuts and V-

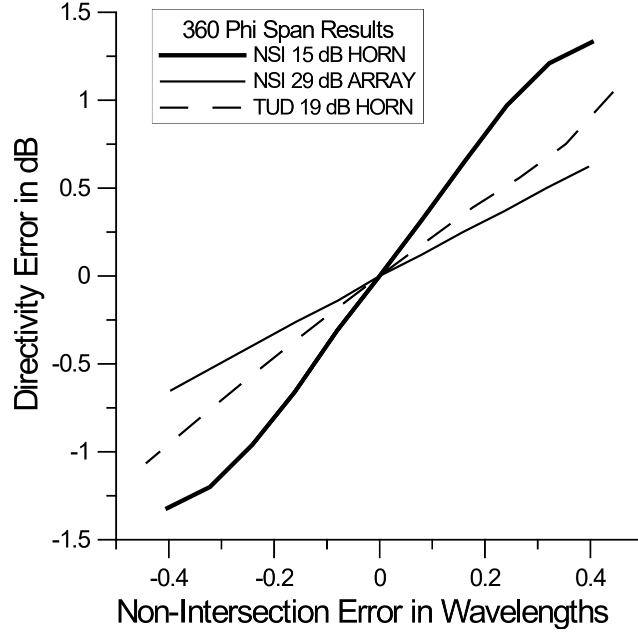

Figure 11 Directivity error as a function of non-intersection error for 360 degree phi span

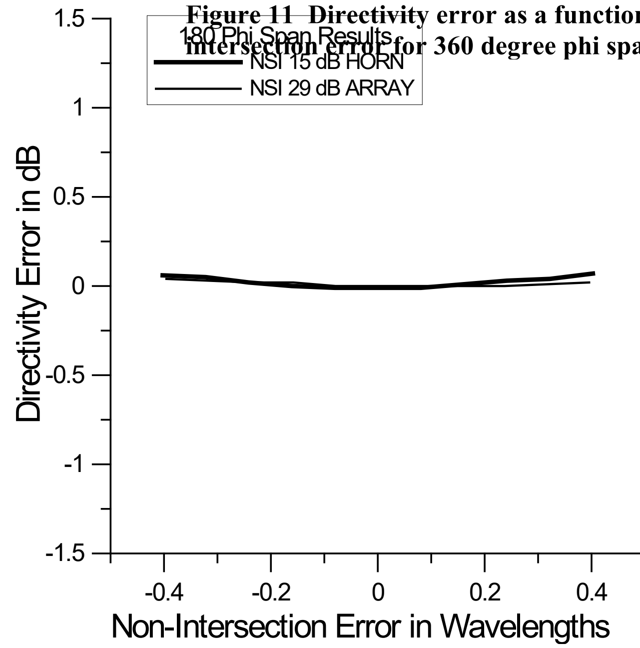

Figure 10 Directivity error as a function of non-intersection error for 180 degree phi span.

cuts for both the horn and the array antennas.

The directivity results are summarized in Figures 10 and 11. The close comparison between the TUD results and the NSI measurements using the 360 degree phi span demonstrates clearly that the reason for the reported difference in sensitivity to non-intersection errors was due to the difference in measurement method. All three of the reported results were correct. No one realized at the time that the scanning method would have such a major effect on alignment errors.

This knowledge can be used to achieve the best results while minimizing the alignment effort. If the major goal of a spherical measurement is the on-axis gain or directivity, the 180 degree phi span measurement will provide the best accuracy for the minimum alignment effort. If the pattern is of major importance, the 360 degree phi span method will provide the best results for a given alignment accuracy. If both pattern and gain are important, or if the scanning method is constrained to one method, the complete results of this measurement study will provide guidelines that can specify the required alignment accuracy for a given parameter and measurement method. Figures 10 and 11 are such curves for directivity. Figures 12-14 have been generated by using the pattern comparison curves similar to Figures 8 and 9. More extensive results will be presented at the Symposium.

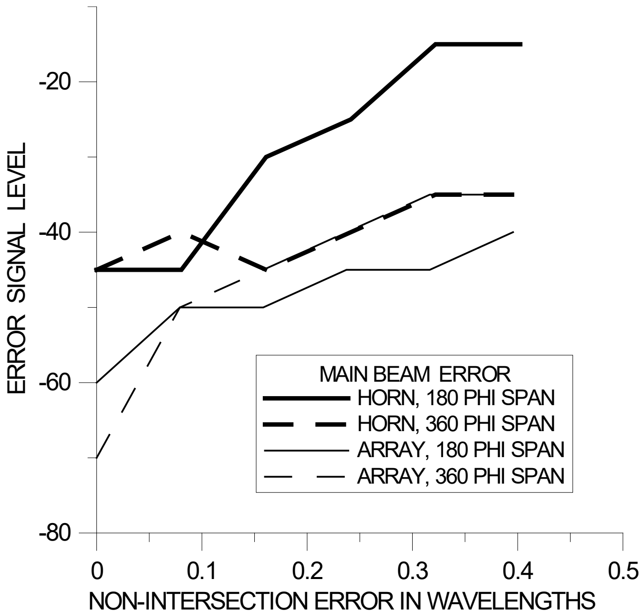

Figure 12 Main beam error, beyond the peak of the beam, due to non-intersection errors.

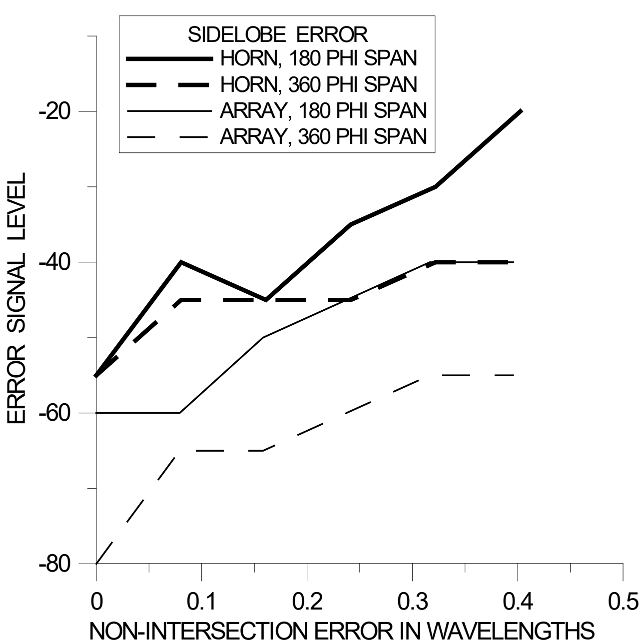

Figure 13 Sidelobe error due to non-intersection error.

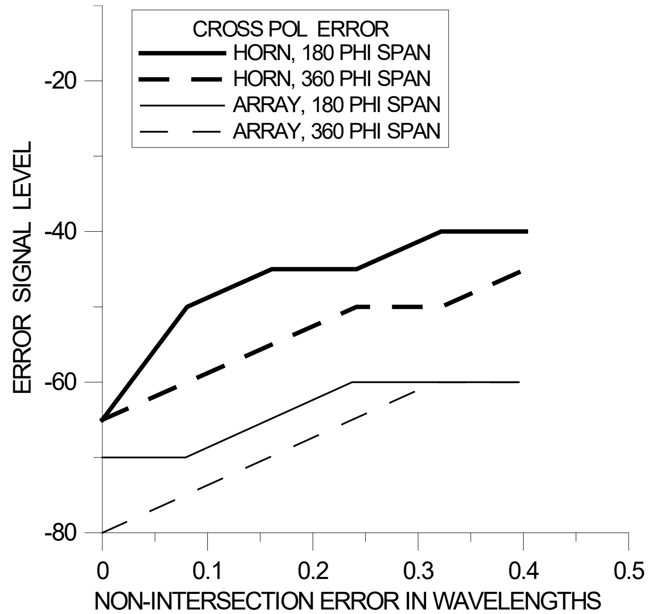

Figure 14 Cross polarization error due to non-intersection error.

5.0 Conclusions

The apparent disagreement between the previous studies has been resolved and found to be due to a difference in measurement methods. Error estimates now include the effect of the measurement techniques.

6.0 Acknowledgement

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