COMPENSATION FOR PROBE TRANSLATION EFFECTS IN DUAL POLARIZED PLANAR NEAR-FIELD ANTENNA MEASUREMENTS

Daniël Janse van Rensburg
Nearfield Systems Inc, 19730 Magellan Drive, Torrance, CA 90502-1104, USA
Tel: (613) 270 9259
Fax: (613) 270 9260
e-mail: drensburg@nearfield.com

ABSTRACT
In this paper a technique is described that allows for the determination and correction of probe translation during polarization rotation in planar near-field measurements. The technique, which relies on the independent translation of coordinate systems for the two orthogonally polarized data sets, has significance for mm-wave testing, where bulky RF components makes probe alignment difficult. Measured data is presented to demonstrate the success of the technique.

Keywords: Antenna measurements, Planar near-field, Measurement errors, Near-field probe correction.

1. Introduction
It is common practice to use a single linearly polarized near-field probe for planar near-field testing of antennas of arbitrary polarization. During such an acquisition two orthogonally polarized data sets are measured. In keeping with the original near-field formulation [1] that requires the use of two distinct probes, this is achieved by simple polarization rotation of a single probe. These two orthogonal data sets are then independently processed to obtain probe corrected far-field radiation pattern information and can be combined to constitute slant linear or circular polarization, depending on the polarization definition required [2, 3, 4]. This polarization processing assumes only rotation of the probe and any translation (which is due to mechanical misalignment of the probe z-axis with respect to the axis of rotation) is usually neglected. For most low frequency applications (< 40 GHz) this is a reasonable assumption. However, for higher frequency applications the physical size of the probe makes mechanical alignment more challenging and when that probe is attached to a bulky mm-wave RF module, the alignment of the entire assembly becomes challenging.

2. Planar Near-Field Theory and Probe Translation
In [1, p. 87] Kerns relates the complex measured voltage on a planar surface to the AUT plane wave spectral function as

\[ b_n(P) = a_n F \int e^{i \vec{K} \cdot \vec{R}} \overline{S}_{\omega} (\vec{K}) \cdot \overline{S}_{10} (\vec{K}) e^{i \omega t} d\vec{K} \]

where the variables are defined as

- \( \vec{P} \) = Vector defining near-field probe location relative to scan plane centre.
- \( \vec{K} \) = Transverse part of propagation vector \( \vec{k} \).
- \( b_n \) = Complex part of propagation vector \( \vec{k} \).
- \( a_n \) = Complex input signal.
- \( F \) = Mismatch correction term.
- \( e^{i \vec{K} \cdot \vec{R}} \) = Phase term relating AUT origin to probe location.
- \( \overline{S}_{\omega} \) = Probe plane wave spectrum.
- \( \overline{S}_{10} \) = AUT plane wave spectrum.

In this paper a technique is described that allows for the correction of any probe translation during this process. A technique is also presented allowing for the automated determination of this probe translation during polarization rotation. With the translation information known, subsequent correction for orthogonally polarized data sets becomes a matter of independent translation of reference coordinate systems.

Section 2 gives a brief overview of the planar near-field theory to describe how probe translation correction is implemented. Section 3 contains measured data for a circularly polarized AUT, demonstrating the success of the correction. In Section 4 a self calibration technique is presented and it is shown how the probe translation distance can be determined through near-field measurement.
In this equation, in order to solve for the complex spectrum of the AUT, two measurement data sets are required. These two sets need to be acquired with near-field probes that have linearly independent spectra [1, p. 90] and in this fashion a set of two equations with two unknowns result.

If the equation shown above is regarded as the first data set, the second (after probe polarization rotation) can be written as

$$b_{0i}(P) = a_{0i} F_s e^{iK \cdot (\overline{T} + \overline{y})} S_{02}(K) S_{10}(K) e^{i\phi d} dK$$

where the new variables are defined as

- $\overline{T} = \Delta x \hat{x} + \Delta y \hat{y}$ = Vector defining rotated probe translation.
- $b_{0i}$ = Complex measured signal for rotated probe.
- $S_{02}$, $S_{10}$ = Rotated probe plane wave spectrum.

In this equation the vector $T$ is the lateral distance displacement of the near-field probe and is ideally zero. However, in order to compensate for any probe translation as considered here a non-zero value can be used and the probe translation can therefore be accounted for.

In taking this approach the assumption is made that there is only a probe translation taking place (no $z$-axis tilt). The probe $z$-axis therefore has to remain orthogonal to the $x$-$y$ plane. Since this method is an attempt to address probe translation for small open ended waveguide probes attached to mm-wave modules and these modules are bulky and usually mounted in sturdy mechanical fixtures on a rotation stage (as shown in Figure 1) alignment of the probe axis to coincide with the stage axis of rotation is very difficult. However, alignment of the probe axis to be orthogonal to the scan plane is not as challenging and since most rectangular open ended waveguide probes have very broad radiation patterns, a slight non-orthogonality can be tolerated. This assumption is therefore not regarded as overly restrictive, but should be noted.

Figure 2 depicts the typical probe translation observed during rotation from polarization position #1 (Pol = 0°) to polarization position #2 (Pol = 90°), where the axis of rotation is the $z$-axis. Measurement of the depicted offset distances defines vector $T$ and therefore allows for compensation of the probe translation.

It is important to realize that although Figure 2 depicts the simple case of the probe being intersected by the $x$ and $y$ axes at the respective polarization orientations, this is not true in general and in such cases $\Delta x \neq \Delta y$.

3. Measured Data Demonstrating Compensation

In Figure 3 the measured near-field intensity is shown for a circularly polarized (CP) horn antenna, measured with a linearly polarized (LP) open ended waveguide probe at 94 GHz. In this instance $\Delta x$ and $\Delta y$ were measured mechanically and determined to be $\Delta x = 4mm (1.25\lambda)$ and $\Delta y = -4.5mm (1.4\lambda)$ respectively. Compensating for this probe translation distance one obtains the far-field result depicted in Figure 4. Figure 4 also shows a reference

![Figure 1: Typical near-field probe mm-wave hardware and fixturing mounted on a planar near-field scanner.](image)

![Figure 2: Probe translation from Pol = 0° position to Pol = 90° position.](image)
pattern, where < 1 mm probe translation was present during polarization rotation. It is clear in this comparison what the impact of the correction is and that the reference pattern can be recovered with reasonable fidelity. As a second test case the same antenna was measured at 94 GHz but with an increased probe translation error of $\Delta x = 2.5 \text{mm} (0.8\lambda)$ and $\Delta y = -9.5 \text{mm} (3\lambda)$. Compensating for this probe translation distance was less successful and a sensitivity analysis indicated that the accuracy of the measured distances was insufficient. This fact again highlighted that this process becomes challenging if probes are physically small and a self calibrating technique has obvious advantageous. Such a technique is presented in Section 4 below.

4. Self Calibration for Determining Probe Translation

The method used is to mount the near-field probe of interest and an AUT and perform a full near-field acquisition with the near-field probe polarization positions $0^\circ$ and $90^\circ$ as depicted in Figure 2. Upon completion, far-field data can be calculated and a phase reference pattern extracted for both the horizontal (azimuth) and vertical (elevation) planes. At this point the measurement is repeated, but in this second instance the near-field probe polarization positions $180^\circ$ and $270^\circ$ relative to that depicted in Figure 2, are used. Using this second data set far-field data can again be extracted and respective phase reference patterns computed. Comparison of these two sets of phase references (where the second set has to be phase reversed due to the inversion of the near-field

Figure 3: Near-field intensity for CP antenna measured with LP probe. $T = 4\text{mm} (x) - 4.5\text{mm} (y)$. Dynamic range shown is 50 dB.

Figure 4: Elevation plane co-polarized (top) and cross-polarized (bottom) patterns for 94 GHz CP horn. Original uncorrected data (red), corrected (blue) and reference data (purple). $T = 4\text{mm} (x) - 4.5\text{mm} (y)$. 

Figure 2: Phase reference patterns (top) and measured intensity patterns (bottom) for CP antenna response.
probe) now gives a direct measure of the probe translation $\Delta x$ & $\Delta y$.

In the test data below probe translation values of $\Delta x = \Delta y = 3\text{mm}$ ($0.23\lambda$ at 23.25 GHz) was introduced as a controlled test distance. The test setup is shown in Figure 5 and the AUT was a linearly polarized (LP) slotted waveguide array, resonant at 23.25 GHz. The antenna was measured with a linearly polarized (LP) open ended waveguide probe and the near-field intensity of the significant polarization component is shown in Figure 6. The data depicts that acquired for the near-field probe position $0^\circ$.

Transforming this data to the far-field, one obtains that shown in Figure 7, where azimuth patterns are shown at the top and elevation patterns are shown at the bottom. Also shown in Figure 7 (overlay) is the far-field data obtained for the near-field probe positions $180^\circ$ and $270^\circ$. The results clearly show no significant difference (despite the near-field probe translation). However, when comparing far-field phase data, the effect of the probe translation is clear and is shown in Figure 8. Only the azimuth patterns are shown, but the elevation patterns display the same phase offset. The difference between the two phase functions is also shown and although this appears to be a linear function it is actually sinusoidal with respect to the azimuth angle. This phase difference can be converted to a linear offset $\Delta x$ using

\[
\Delta x = \frac{\Delta \text{Phase}}{2\pi \sin \theta}
\]

Figure 6: Near-field intensity for LP slotted waveguide array measured with LP probe (orthogonal polarization component is not shown since amplitude < -50 dB). Dynamic range shown is 50 dB.

Figure 7: Azimuth LP co-polarized (top) and elevation (bottom) patterns. Probe position 0/90 data (red) and probe position 180/270 (blue).
Figure 9 shows the function obtained as well as an average value for $\Delta x$ in mm (2.98 mm). Repeating this process for the elevation plane, Figure 10 results with an average value for $\Delta y$ in mm (3.04 mm). Both values closely resemble the actual probe offset values of $\Delta x = \Delta y = 3\text{mm}$.

![Figure 8: Far-field azimuth pattern phase data comparison showing the 3 mm probe translation effect.](image)

Using these values for correction of the probe translation, the azimuth and elevation phase patterns in Figure 11 are obtained. The original uncorrected data, the corrected data and the reference data is shown. The technique compensates successfully for the probe translation in both planes and one is able to recover the far-field phase.

This data therefore confirms that calculation of a phase reference position based on two near-field acquisitions can provide a measure of the near-field probe translation vector $T$ without making any mechanical measurement. This type of calibration can be performed at a single frequency, once a near-field probe has been mounted and the information can then be used for all subsequent measurements at all frequencies to correct for the probe translation.

5. Conclusions

This paper presents a technique that allows for the correction of planar near-field probe translation during polarization rotation. The significance of this correction is that with the growing number of mm-wave applications and the bulk of mm-wave hardware directly attached to the near-field probe, probe alignment becomes increasingly difficult and this method provides a way to correct for such anomalies. With ever decreasing wavelength, satisfactory mechanical alignment may ultimately become unfeasible and this technique may provide a way to overcome this problem. Results showing the successful correction of near-field data taken at 94 GHz are presented to support this.
A self calibration technique is also described that allows for the detection of the near-field probe translation distance through analysis of the near-field measured data. This technique circumvents the problem of having to make mechanical measurements of the probe alignment. The advantage of this technique for mm-wave applications is significant and it further allows for full automation of the correction process.

Figure 11: Far-field azimuth (top) and elevation (bottom) phase data comparison demonstrating the \( T = 2.98 \text{mm (x)} + 3.04 \text{mm (y)} \) probe translation correction.

6. REFERENCES


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