Reducing Measurement Time and Estimated Uncertainties for the NIST 18 Term Error Technique

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ABSTRACT

This paper describes some improvements in the measurement process of the NIST 18 term error analysis that reduces the required measurement time and also improves the sensitivity of some of the tests to the individual sources of uncertainty. As a result, the measurement time is reduced by about 40 % and some of the estimated uncertainties are also improved without a reduction in the confidence levels. The reduction in measurements is accomplished by using one measurement for two or more error terms or using centerline rather than full 2D data scans for some of the terms.

Keywords: Antenna Measurements, Error Analysis, Near-Field Measurements

1.0 Introduction

The NIST 18 Term Error Analysis Technique[1] uses a combination of mathematical analysis, computer simulation and near-field measurements to estimate the uncertainty for the results of near-field range measurements on a given antenna/probe combination and frequency range. Nine of the terms can be evaluated using mathematical analysis and do not require any special near-field measurements. The measurements for the remaining nine terms can be time consuming and require high stability and repeatability of the measurement system. In a typical evaluation, the equivalent of at least 25 complete near-field measurements must be obtained on the AUT under carefully defined conditions. Improvements in the process have recently been developed and applied to a planar near-field facility that reduces the number of measurements to 16 and also makes it possible to improve some of the uncertainties to the actual system performance rather than the limits of the measurement process. The improved process will be described and examples shown for a planar near-field range.

2.0 NIST 18 Term Error Analysis Procedure

The individual terms in the error analysis process are listed in Table 1. The first nine do not require any near-field RF measurements on the antenna under test (AUT) and are evaluated using derived equations. Note that the terms have been reordered to group the analysis terms together. The input data for the equations comes from the calibration data on the probe and/or gain standard, impedance measurements on the transmission line components, alignment data on the AUT and probe and position error data obtained from optical measurements on the mechanical scanner.

The remaining nine terms are evaluated using a self comparison measurement process. This process depends on the stability and repeatability of the AUT, probe and the total measurement system. It does not depend on a knowledge of the "true" properties of the AUT and none of the terms are derived from a comparison of results with a known or ideal far-field pattern. An estimate of the uncertainty for each term is obtained by comparing two or more near-field measurements that are identical in all respects except for one carefully controlled difference. The difference can be in the calculation process such as truncating the near-field data to produce a smaller scan area or in the measurement setup such as changing the z-separation distance between the AUT and probe. If the system is stable and the measurement changes are carefully chosen, the difference between the resulting far-field patterns will be due to a single error term and provide an estimate of the uncertainty due to only that term. This process requires a reference measurement and one or more additional measurements with changes induced in the system and the typical numbers of measurements for each term are shown in Table 1. For the usual approach, the equivalent of at least 25 near-field measurements must be completed to evaluate all the terms. A complete near-field measurement is defined as one with approximately half wavelength spacing in both X and Y directions, two polarizations and covering an area large enough to minimize the truncation error. If the testing involves multiple beams or multiple frequencies the scan speed must be adjusted for these conditions.

Table 1 Summary of the NIST 18 Term Error Model.

		Number of Tests Required	
Error Source	**Primary Evaluation Method**	**Original**	**New**
Probe relative pattern	Analysis		
Probe polarization ratio	Analysis		
Probe gain measurement	Analysis		
Probe alignment error	Analysis		
Normalization constant	Analysis		
Impedance mismatch	Analysis		
AUT alignment error	Analysis		
Probe x, y-position errors	Analysis		
Probe z-position errors	Analysis		
Data point spacing	Measurement	3	2
Meas. area truncation	Measurement	1	1
Multiple reflections (probe/AUT)	Measurement	5	5
Receiver amplitude nonlinearity	Measurement	4	1
System phase error due to:			
Flexing cables/rotary joints	Measurement		
Temperature effects	Measurement		
Receiver phase errors	Simulation		
Receiver dynamic range	Measurement	3	3
Room scattering	Measurement	2	2
Leakage and crosstalk	Measurement	2	2
Random errors in amplitude/phase	Measurement	5	0
		25	16

The data point spacing tests requires the equivalent of three full measurements since one is taken with quarter wavelength spacing requiring at least double the measurement time and another is taken at the regular spacing for comparison. In the case of multiple reflections and random errors, multiple measurements are required so they can be averaged to provide a reference result that has a reduced level of the error term.

The setup, measurement and analysis of each of the 25 measurements can be time consuming and typically will require on the order of one week to complete using the original approach. If a gain standard is used as the reference for gain measurements, additional comparison measurements must be performed on the gain standard/probe for at least the truncation, multiple reflections and room scattering terms. In the following sections, improved procedures will be described that reduce the number of measurements or the time required for a given measurement while at the same time improving the sensitivity of the results.

3.0 Measurement System and Antenna

The measurement system being evaluated was an NSI combination planar/cylindrical scanner with a maximum scan area of 12 by 12 feet that was installed at L-3 Communications, CS-W in Salt Lake City, UT . The AUT was a circularly polarized planar array with input feeds for both WR42 and WR22 waveguide bands and tests were carried out in both bands. The antenna was designed and developed by ThinKom Solutions, Inc. and was very well suited for use in the range evaluation since it was very stable, could be aligned accurately to a mechanical reference and had a very narrow beam that is appropriate for the planar measurements. In addition, the array elements produced a multiple reflection characteristic that occurs only with a periodic structure and demonstrates how this can affect the choice of data point spacing.

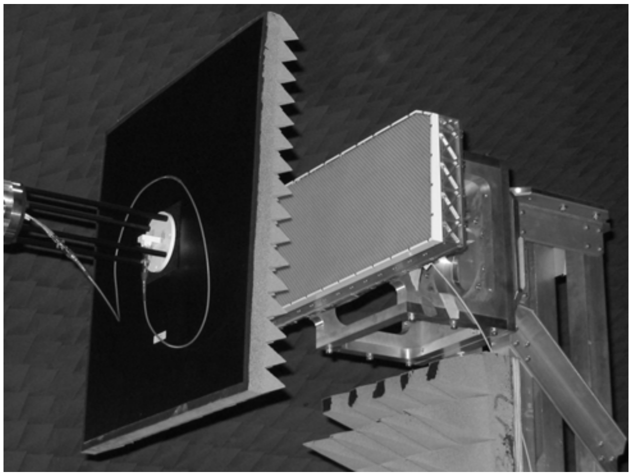

Figure 1 Antenna used in range evaluation.

4.0 Combining Data Point Spacing and Random Error Tests

As shown in Table 1, the data point spacing and random error tests normally require a total of eight near-field measurements. With the new approach, this is reduced to a single reference measurement at the quarter wavelength spacing which takes the same time as two regular measurements. Instead of taking another measurement at half wavelength spacing to compare with the reference, a script was developed that would produce a new data file by setting the amplitude of every other point in both X and Y to zero. The far-fields of the reference and thinned files were then compared to produce estimates of uncertainty between quarter and half wavelength spacing. In addition to reducing the measurement time, this procedure is also less sensitive to drift, slight differences in cable flexing errors and room scattering changes that might occur between two completely different measurements.

A method was also developed to use the quarter wavelength data to estimate the random error signal level without additional measurements. If the angular spectrum of the measured data is computed without applying either the probe correction or the Cos(θ) factor, the resulting spectrum will cover a span in normalized k-space $\left(\frac{k_x}{k},\frac{k_y}{k}\right)$ from -2 to +2 as shown in Figure 2. The portion of the spectrum within the unit circle is produced primarily by the AUT with relatively small contributions from all sources of measurement error. The portion of the spectrum outside of the unit circle also has contributions from both the AUT and measurement errors, but the AUT component is exponentially attenuated since the AUT plane waves in this region are evanescent modes. The spectrum in this region is therefore dominated by measurement error sources that have a near-field period of less than one RF wavelength. Experience has shown that the two primary error sources are modulation of the multiple reflection signals by the periodic structure of the AUT array and random errors from all electrical and mechanical sources. The localized peaks in Figure 2 can be identified with the multiple reflection mechanism and these lobes in the evanescent region must be considered when selecting the data point spacing. If far-field pattern results are required over the full front hemisphere, and a minimum aliasing error is desired, the data point spacing must be chosen using a band limit that is larger than the k-value of the last lobe. In Figure 2 the last lobe due to the multiple reflections is at $\frac{k_x}{k}=1.3$ and the required data point spacing is 0.38λ as calculated from,

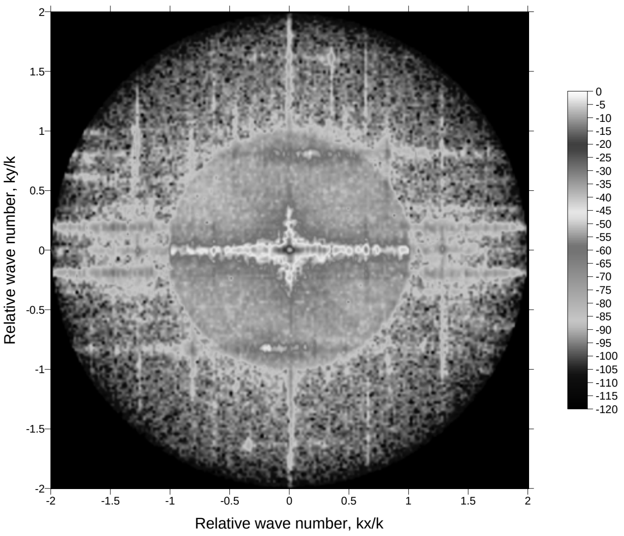

Figure 2 Plane-wave spectrum of the measured data from quarter wavelength spacing data.

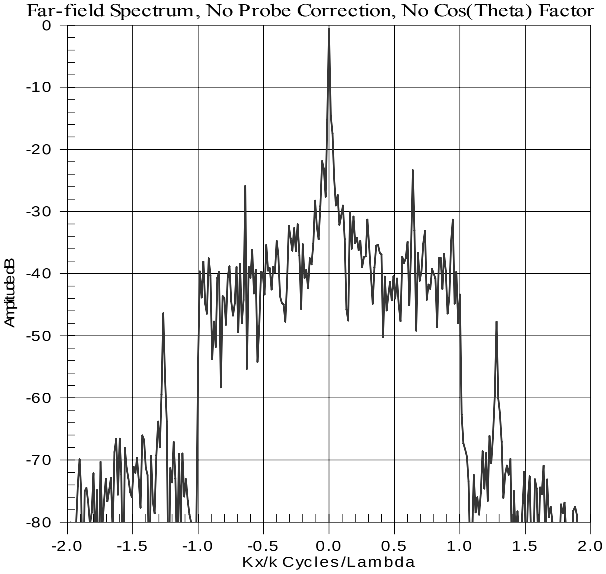

Figure 3 Single cut of plane wave spectrum from quarter wavelength measured data.

$$\delta_{x-\max} \le \frac{\lambda}{2\frac{k_{x-Lim}}{k}}$$

$$where \qquad (1)$$

$$k_{x-Lim} = \text{spectrum cutoff band limit}$$

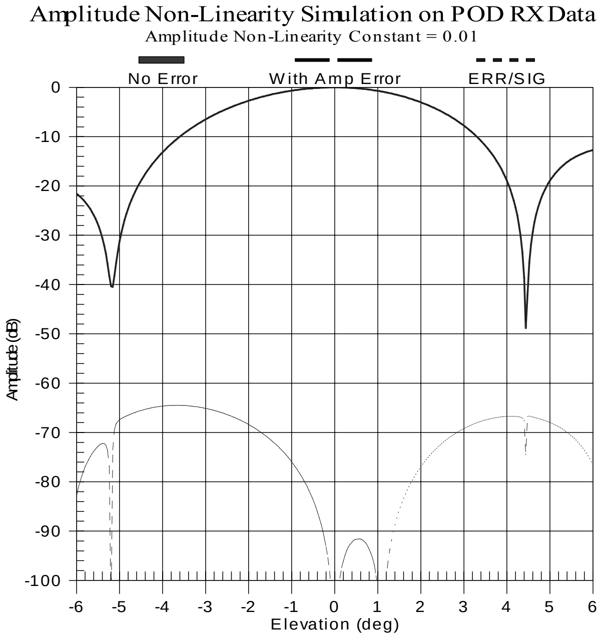

Figure 4 Results of amplitude non-linearity simulation showing characteristic difference pattern.

The comparison of the far-field from the reference quarter wavelength and thinned data will also show the aliasing error due to the multiple reflection lobes. If the far-field pattern is not required over the full hemisphere, a larger spacing can be determined from the equations

$$\delta_x \le \frac{\lambda}{\left[k_{x-Lim} + k_{x-\max}\right]} \qquad \delta_y \le \frac{\lambda}{\left[k_{y-Lim} + k_{y-\max}\right]}$$

where

$k_{x-\max}$ and $k_{y-\max}$ are the boundries for the region of interest

(2)

The random error level is estimated from the "noise" level of the spectrum in the evanescent region. Excluding the localized peaks due to the multiple reflections, the random error level is at least 70 dB below the peak of the main beam. Using this approach, five measurements are eliminated, and the error level is not influenced by drift, or changes in room scattering and cable flexing between repeat measurements.

5.0 Estimating Receiver Non-Linearity Errors

In the past, non-linearity has been estimated by comparing the far-field results of measurements where the input power level to the mixer was changed along with the receiver averaging to maintain a constant signal-to-noise ratio. Computer simulation has shown that the primary effect of receiver non-linearity is a change in the main-beam width and so a pattern difference similar to Figure 4 was expected and used as a measure of the receiver non-linearity. However the measured differences rarely show this regular pattern since the non-linearity of most receivers is very low and usually less than random and repeatability errors.

In principle, the linearity could be checked using a highly repeatable step attenuator and phase shifter. If the receiver is linear, the observed change in amplitude or phase for a given switch should be independent of the power level to the mixer. The receiver averaging can be increased to reduce the effect of random errors and this measurement can be completed fairly quickly. Reliable and repeatable step attenuators and phase shifters are generally not available in all the frequency bands where range evaluation is performed, so this approach is not generally used. A variation of this approach has been developed and used in the current range evaluation with very good success.

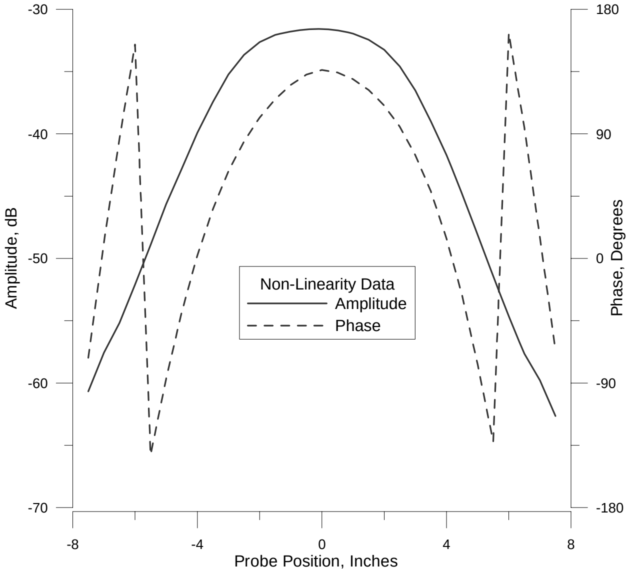

Figure 5 Sample near-field centerline data used for non-linearity tests.

The variation uses a portion of the centerline near-field data to produce repeatable changes in amplitude and phase as shown in Figure 5. The receiver averaging is

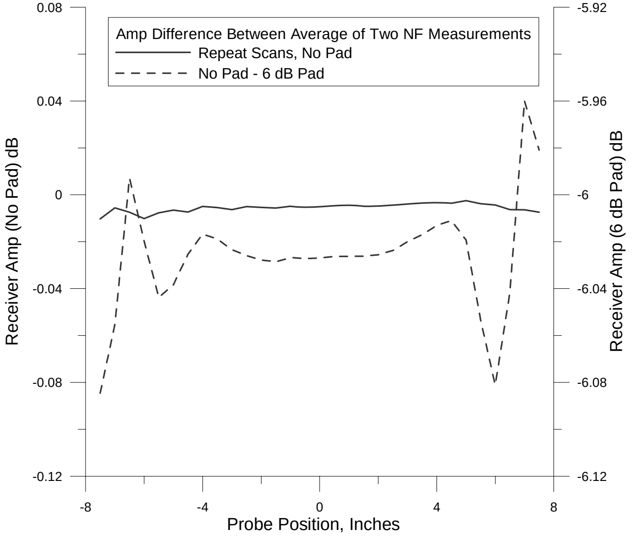

Figure 6 Amplitude difference between average of six repeat near-field centerline scans to measure amplitude non-linearity.

increased to the maximum to reduce random errors, the probe is stopped at each data point to reduce position errors, and the centerline is scanned in both the plus and minus directions and then averaged to reduce the effect of drift and cable hysteresis. Typically 6-8 bidirectional scans are made along the same centerline with an amplitude variation of approximately 20-30 dB and then averaged using a script. Comparison of the averages from two or more repeat measurement sets demonstrates the level of repeatability. The process is then repeated for different levels of power to the mixer. Figure 6 shows one result where the measurement is repeated without any change in mixer power level and then a six dB pad is inserted before the mixer. Without any change, the amplitude difference is constant to within 0.005 dB which indicates the stability and sensitivity of the test. When the pad is inserted, a small and repeatable non-linearity is clearly observed with a maximum deviation of less than 0.1 dB over the 30 dB dynamic range. A similar result is seen in the phase difference plots as shown in Figure 7. Without any mixer power change, the phase differences are less than 0.05 degrees while with the pad added, the non-linear error is on the order of 0.3 degrees. It is possible that the observed variations are due to something other than non-linearity. At this level, changes in impedance mismatch or interference signals could produce some or all of the changes in the measured amplitude or phase. But this result does set an upper limit to possible receiver non-linearity and this limit is much lower than available from previous tests. This is because the new test can isolate the non-linearity error from other sources that would be embedded in the result from the normal full 2D measurements.

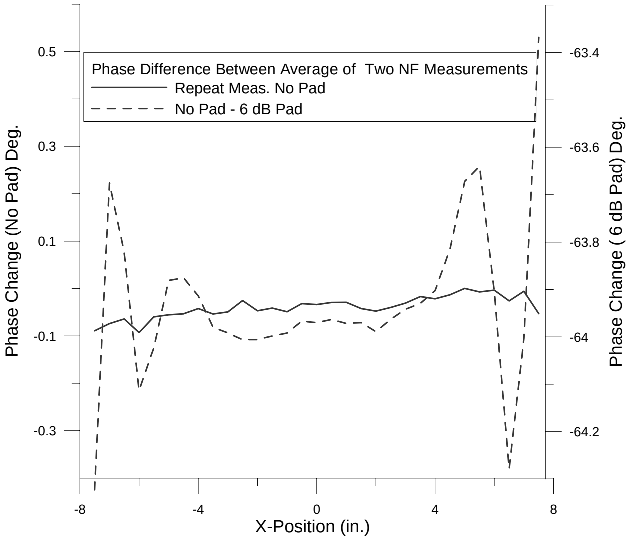

Figure 7 Phase differences between average of six repeat near-field centerline scans to measure phase non-linearity.

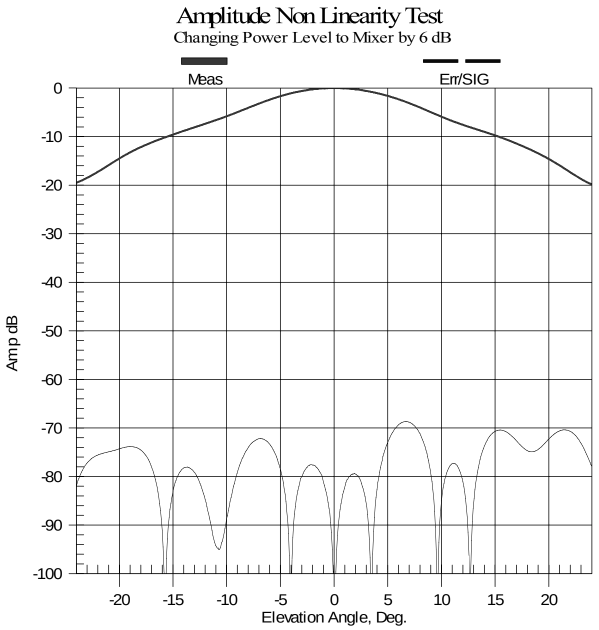

Figure 8 Error signal level in the far-field due to non-linearity.

The approximate effect on far-field parameters is obtained by computing the far-field patterns from the centerline scans and calculating the error signal level from the difference in the patterns as shown in Figure 8. The very small linear phase variation shown in Figure 7 will produce a small offset in the peak of the main beam that is not due to non-linearity but will produce the same difference curve as non-linearity. Therefore, one beam is shifted to precisely align the beam peaks and remove this effect before calculating the error signal level. The end result in this case demonstrates that the non-linear error signal is at least 70 dB below the peak of the main beam.

Typical levels using previous methods were in the range of 50 to 60 dB and so this is a big improvement.

6.0 Summary

New procedures have been described and illustrated with recent measurements that reduce the time required for performing the NIST 18 Term Error Analysis process. They also generally produce lower estimates of the error signals due to aliasing, random errors and non-linearity.

8. REFERENCES

[1] A. C. Newell, Error analysis techniques for planar near-field measurements, IEEE Trans. Antennas & Propagation, AP-36, p. 581, 1988.

9. ACKNOWLEDGMENTS

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