Antenna Pattern Comparison Using Pattern Subtraction and Statistical Analysis

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Abstract— **This paper discusses a technique that can be used when comparing two antenna patterns that produces a measure of the difference between the patterns and an associated confidence level for the results that is derived from a statistical analysis of the pattern differences. The first step in the process is to verify that the same coordinate system is used, and that the AUT is precisely aligned to those coordinates in all measurements. Small differences in beam pointing and polarization that correspond to rotations about the three rectangular axes can arise due to AUT alignment differences or due to some measurement errors. These changes in beam pointing can produce apparent pattern differences in the pattern comparison process that can distort the results, and adjustments in the AUT alignment or pattern data should be done before the pattern comparisons are carried out. It is easy to interpolate the pattern or change the pattern centering using standard processing software to try and correct for the angular misalignments, however the interpolation or centering may not completely correct for rotations about all three axes and some effects may remain after software adjustments. The next step in the process is to separate the analysis of pattern differences in the main beam region from those in the sidelobe region. The main beam region is analysed by focusing on beam pointing, peak gain, directivity and beam width comparisons. For sidelobe and cross polarization comparisons, the patterns are normalized to the peak of the main beam for each measurement rather than to the directivity or gain of results. This will separate changes in main beam parameters from sidelobe differences. The normalized patterns are then compared by calculating the difference between the two patterns and from these differences the ratio of an Equivalent Stray Signal (ESS) to the peak of the main beam is derived. The derived ESS will generally have large variations over the angular extent of the patterns. A statistical analysis of this ratio produces a single ESS that is constant over the full angular extent that is a measure of the difference of the patterns along with a confidence level for the ESS. The derived ESS can then be used as an estimate of uncertainty for a measurement error source such as reflections, data point spacing, etc. It can also be used to quantify the difference between measurements on different ranges or using different techniques. Example of both of these applications will be presented.**

I. Introduction

There are many situations in antenna measurements where it is desirable to compare two or more results and derive a measure that quantifies the difference between the results. This often arises in estimating the uncertainty in a measurement or comparing the results of measurements performed on different ranges or using different measurement techniques. The value of the derived difference or estimate of uncertainty is greatly increased if a confidence level can be associated with the result. This is easy to accomplish if the differences between measurement results are primarily due to random errors, the measurement can be repeated many times and a distribution can be obtained. Statistical methods can then be applied to determine the standard deviation and other measures of the distribution. The estimated uncertainty is then a multiple of the standard deviation and the associated confidence level follows directly. This process is much more difficult when the differences between results or the error sources being evaluated are primarily due to systematic type error. For instance if one is attempting to estimate the uncertainty in the sidelobe pattern results due to multiple reflections in a planar near-field measurement, the error in any given sidelobe for a fixed range configuration will be the same for repeated measurements. The separation distance between the AUT and the probe can be varied in $\lambda/8$ increments and the measurement repeated at four or five different distances. The difference between the average of the results and a single measurement can be used as a measure of the uncertainty and this is often done in performing error analyses. The limited number of measurements will not produce a distribution for any given sidelobe that can be used for a statistical analysis and so it is difficult to determine a confidence level for the estimated uncertainty. Similarly, when the antenna patterns from two different ranges are compared, the primary error sources that produce differences in results are due to systematic type errors. Even if multiple measurements are made on both ranges, it is not practical to derive a distribution that will include the effects of both random and systematic errors and lead to statistical analysis.

Earlier efforts to derive quantitative measures of comparison between antenna pattern results using statistical methods have been reported [1,2,3,4,5]. In the following paper, a method will be described that can also provide an estimate of the uncertainty in the AUT pattern results due to individual error sources along with a confidence level. The primary difference between earlier techniques and the one reported here is that it does not require large amounts of repeat measurements to produce a statistical distribution and the analysis techniques are much less complex. This approach can also be used when estimating uncertainty in a measurement or comparing results from different ranges to give a concise measure of the difference between the pattern results. Example of both applications will be presented.

II. Coordinate System and Beam Pointing

In any comparison of antenna patterns, it is essential that all of the results use the same coordinate system and definition of vector components. This is especially true when comparing results from different ranges or from different measurement techniques. The AUT Cartesian coordinate system must be defined using mechanical or optical references so that it can be precisely aligned to the reference coordinate system of the measurement range. Even small misalignments will cause large apparent differences in the comparisons between patterns. This is illustrated in Figure 1 where two patterns are compared using a graphical technique that will be

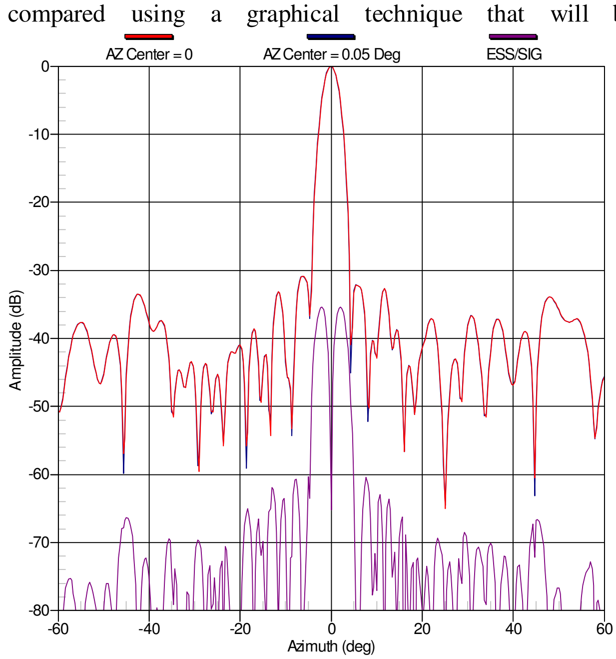

Figure 1 Simulated pattern comparison where the second pattern is identical to the first but shifted by 0.05 degrees.

used throughout this paper. The two patterns are first overlaid and in this case they appear to be identical since the second pattern is identical to the first one but has been shifted in azimuth by 0.05 degrees to simulate a misalignment. The software used to produce the graphics then computes the difference between the patterns, Δ at each point and also computes and plots an Equivalent Stray Signal (ESS) level relative to the peak of the main beam. The ESS is related to the difference between the patterns by the equation,

$$ESS/SIG = 20 * \log\left[10^{\left(\frac{\Delta_{dB}}{20}\right)} - 1\right] \qquad (1)$$

The ESS is a measure of the pattern comparison and as shown in Figure 1, it appears that there is a large difference in the main beam region of approximately -35 dB and this is completely due to the simulated misalignment.

There are two techniques that are used to reduce the effect of misalignment on the computed ESS level. The first uses a manual adjustment of the beam centering in the software to correct for small beam shifts. The required shifts can be determined initially by examining expanded plots of the main beam peak as shown in Figure 2 and then finer adjustments made by changing the offsets and recalculating the ESS until the minimum value in the main beam is achieved.

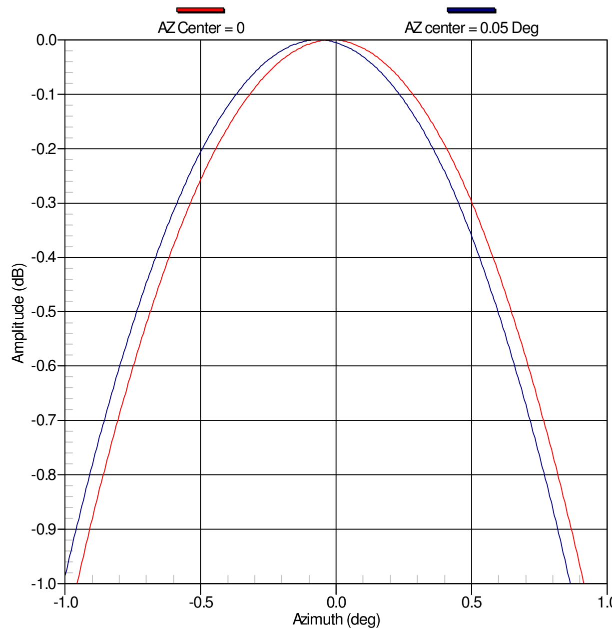

Figure 2 Expanded main beam plots used to estimate beam offset errors.

The second technique separates the pattern comparison into two regions. The main beam parameters such as gain, directivity, beam width and far-field peak are tabulated for each of the patterns and the variations of these parameters is used to quantify the differences in the main beam region. Outside of the main beam region, the ESS is used as the measure of difference between the two patterns.

III. Statistical Analysis Using the ESS

There are a number of ways that the ESS can be used to derive a quantitative measure of the difference between two or more patterns. In the following discussion we will use the example of comparing two patterns to estimate the uncertainty due to a single error source in an 18 term uncertainty analysis [6]. When pattern comparison of the results of near-field measurements are used to estimate the uncertainty, the tests use a self comparison approach which does not depend on knowing the true antenna parameters or even assuming that the results of a given measurement are free from other sources of error. The tests are designed to be sensitive to only a single error source and ideally the difference between two or more measurements will quantify the uncertainty for a single term. For instance in the case of a spherical near-field range that has errors in the intersection alignment of the theta and phi axes, the antenna patterns calculated from measured near-field data would not produce the correct results because of alignment error and other error sources. But if the alignment errors and all the other systematic errors are repeatable for a given measurement configuration, the far field results should also be repeatable. When pattern comparison is used to estimate the uncertainty due to multiple reflections, the z-distance between the AUT and probe is changed in small increments over a half wavelength interval, measurements are repeated and the far-field pattern computed from each measurement. The effect of alignment errors and all the other systematic errors with the exception of the multiple reflection errors should remain constant and the changes in the far-field results are due primarily to the multiple reflection. This term can be quantified with the multiple z test even though there may also be a larger but constant error term due to the misalignment. In each of these self comparison tests, plots like Figure 1 are produced and the ESS pattern is produced. As seen in Figure 3, that is the result of a multiple reflection test in a planar measurement, the ESS level will generally have large variations over the angular region and a decision must be made on what value to use as the uncertainty for a given sidelobe level or for a given individual sidelobe at a specific

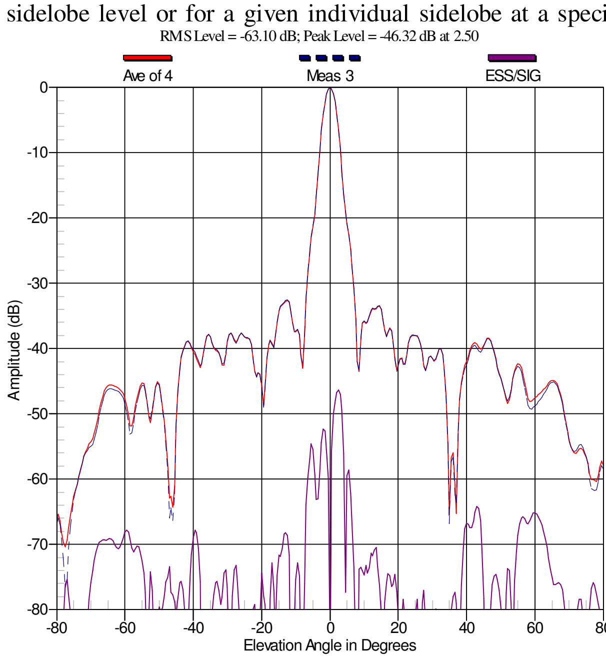

Figure 3 Comparing the far-fields computed from the average of four measurements at different z-distances with a single result to estimate multiple reflection uncertainty.

angle. If the focus is on a particular sidelobe such as the peak sidelobe, we may consider using the value of the ESS at that specific angular location. However the pattern comparison process does not produce the actual error at a specific location since neither of the patterns being compared is the "true" value. The ESS is an estimate of the uncertainty and for a specific angle may be higher or lower than the actual error. The value and confidence level of the estimated uncertainty could be greatly improved if there was some way to repeat the process and produce a distribution of uncertainties from which a standard deviation and confidence level could be derived. It is not practical to produce such a distribution for a specific angle since the pattern differences are caused by a systematic errors that would produce the same results for repeat measurements on the same AUT/probe/distance combination. But the ESS pattern as a function of angle can be viewed as a distribution of the estimated uncertainty that can be applied to any angular position. Using this approach, we assume that there is an ESS due to multiple reflections that has the same magnitude over the full angular region and the ESS curve as a function of angle is a distribution of estimates of this constant value. If in fact the actual ESS is not approximately constant over the full angular range, the estimated uncertainty may be less reliable in some regions. The Root Mean Square (RMS) value of the ESS curve is then the standard deviation of the distribution and the RMS can be used as an estimate of the ESS at every angle. In the example of Figure 3, the RMS is calculated as -63 dB and this is the estimate of the ESS that would be used to determine the uncertainty in at any given sidelobe level using the inverse of Equation 1,

$$\text{Sidelobe Uncertainty in dB} = \Delta_{dB}$$

$$\Delta_{dB} = 20 * \mathbf{log}\left[1 + 10^{\left(\frac{ESS - SL}{20}\right)}\right] \qquad (2)$$

$$where\ SL = \text{ Sidelobe level in dB.}$$

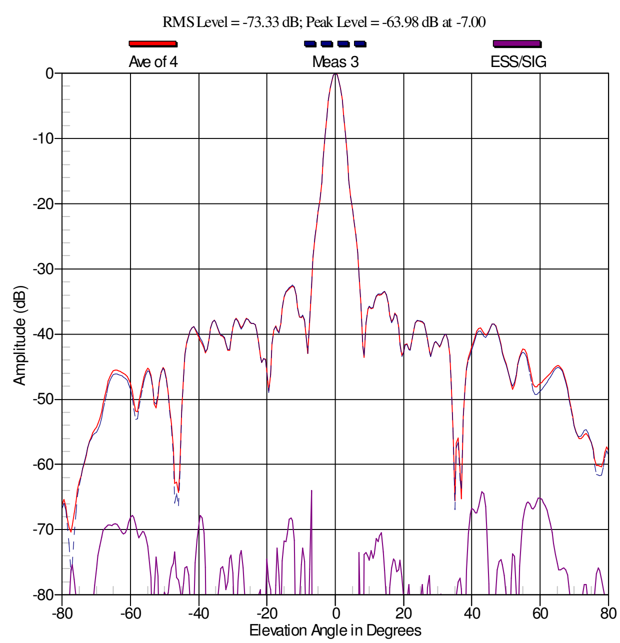

Figure 4 Pattern comparison results after excluding the main beam region of the pattern.

When this approach is used to estimate uncertainty in sidelobe level, three adjustments are made that will focus on the sidelobe region and will also increase the confidence level in the result. In the first adjustment, the patterns being compared are normalized to the peak of the main beam of each pattern so that the comparison is between relative rather than absolute sidelobe levels. In the second adjustment illustrated in Figure 4, the main beam region is excluded from the calculation of the RMS. As previously mentioned, the main beam parameters of gain, directivity and peak far-field are used to characterize the main beam region. By excluding the main beam region in the calculation of the RMS, the effect of residual misalignments as illustrated in Figure 1 are eliminated and the calculated RMS focuses on the sidelobe region. For the example illustrated in Figures 3 and 4, the RMS has been reduced by approximately 10 dB by excluding the main beam region, and this is typical for these types of comparisons. In the final adjustment, a multiple of the RMS is used to increase the confidence level in the estimated uncertainty. Since the RMS represents the standard deviation of the estimate of the uncertainty, it will have a 39.4% confidence level associated with 1σ. Increased confidence levels of 86.5% or 98.9% can be achieved by adding 6 dB or 9.5 dB respectively to the calculated RMS corresponding to 2σ or 3σ.

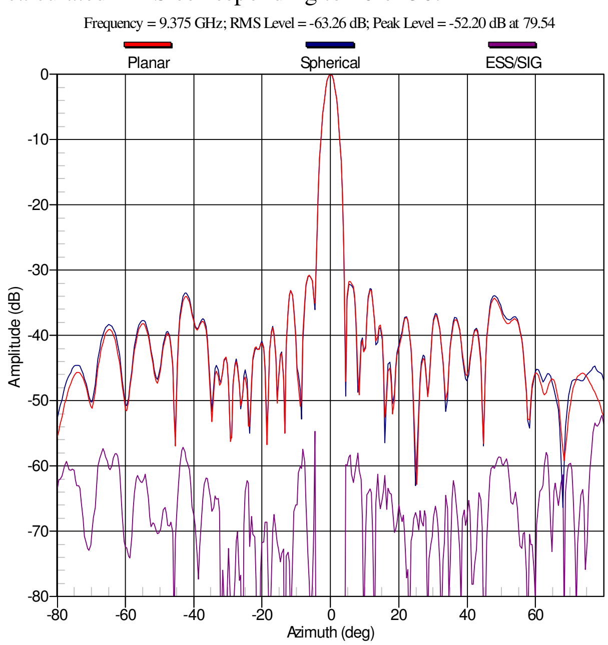

Figure 5 Example of pattern comparison between a planar and spherical near-field range.

Using this pattern comparison procedure and the results illustrated in Figure 4, the ESS level with a confidence level of 98.9% is estimated to be -63.8 dB relative to the peak of the main beam and -23.8 dB relative to a -40 dB sidelobe. The uncertainty in a -40 dB sidelobe due to multiple reflections at any angle in the pattern is therefore 0.5 dB.

Figure 5 shows a pattern comparison result for measurements on different ranges. The test antenna was measured on both planar and spherical near-field ranges and special care was taken to precisely align the antenna to the reference range coordinates. Figure 5 shows the results of the pattern comparison for the sidelobe region. Using a confidence level of 98.9%, the ESS difference between the ranges is estimated to be -54 dB.

IV. Conclusions

A pattern comparison technique has been developed and used on a number of different ranges and AUT types and has been found to be an effective method to quantify the estimated uncertainty in a single measurement or to quantify the difference between results on different ranges. The method provides a means to determine a confidence level associated with the estimated uncertainties and therefore improve the reliability of both the individual estimates and the combination of the individual items in estimating the total uncertainty in a measurement.

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