MEASURING WIDE ANGLE ANTENNA PERFORMANCE USING SMALL PLANAR SCANNERS

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ABSTRACT

A technique for the prediction far field antenna patterns from data obtained from non-coplanar partial scans is presented. The applicability of this technique in the measurement of antenna assemblies in planar facilities that would normally be considered too small to acquire suitable near field data, sufficiently free from truncation, is illustrated.

The accuracy of the transformation technique is assessed via the application of a novel statistical measure of association. The derivation of this metric of association is accomplished through an unconventional analysis of the ordinal aspects of the predicted far field interval data. The limitations of the technique are explored and the directions to be followed in subsequent research are discussed.

INTRODUCTION

It is well known that far field antenna parameters such as pattern, gain, directivity, beamwidth, *etc.*, can be derived analytically from near field measurements (1). For such parameters, which are not obtained directly from measurements made in the near field, a transformation from one spatial domain, or surface, to another is necessitated.

This transformation, of monochromatic but otherwise arbitrary waves, can be accomplished by representing the field at an arbitrary point in space as an integral over the surface on which the fields are known (2). Alternatively, considerable computational advantages can be obtained by representing the field as a summation of any elementary wave solutions to Maxwell's equations (3). Here, the coefficients to these solutions are determined by matching the fields on the surface on which the fields are known and by using mode orthogonality. Solving this modal expansion for the fields at an infinite distance from the radiator results in the far field pattern.

In the latter case a degree of mathematical convenience can be obtained from selecting a modal basis that matches the measurement geometry, *i.e.* by utilising plane waves, cylindrical waves, or spherical waves respectively for the case where the measurements are taken over planar, cylindrical or spherical surfaces. The principal factor in determining the complexity of 1; the near field to far field transformation 2; the probe directivity pattern correction 3; the extent of the truncation of the data, is the geometry of the surface over which the near field is sampled, and its associated orthogonal modal basis.

For the case of the planar near field methodology, if the forward hemisphere is to be determined exactly, the propagating field must be sampled either in the aperture of the antenna or over a plane of infinite extent. In practice, due to the finite extent of the scan plane any conventional planar near field measurement will inevitably represent a truncated data set, and as such, any predicted far field pattern will include errors associated with this truncation. Furthermore, the precise nature of this effect is complicated, as a variation in any part of the near field pattern will necessarily, as a consequence of the holistic nature of the transform, result in a change to every part of the corresponding far field pattern.

However, it is the data that is transformed to produce the far field pattern that is required to be free from excessive truncation. If this data is the product of the combination of a number of partial data sets that, in contrast to the single scan data set, fulfil the transformation requirements in terms of sampling rate and continuity over the sampling interval, then the prediction will be free from truncation errors.

Hitherto, the problem of truncation in near field data acquired over a planar surface has been partially addressed by combining data sets that have been acquired via a series of coplanar transforms, *e.g.* translations or rotations (4). However, techniques involving spatial translations of the antenna are dependent upon the additional availability of a specialist precision antenna positioning subsystem. Such sub-systems, with the ability to translate the antenna accurately and with sufficient repeatability in a plane tangential to that of the scanner, as a result of the antenna translation, occupy large volumes. Additionally the translation of the antenna involves the movement of parts of the RF interference network of the measurement systems, and this will introduce phase errors in the measurements, which must be either corrected or minimised.

These techniques essentially involve the extension of the size of the existing scan plane by the systematic synthesis of a composite data set from a combination of partial data sets acquired via a series of coplanar translations and/or rotations. However, this strategy, although it can significantly improve the performance of the measurement facility, can never entirely succeed since any finite number of translations or rotations can *never* synthesise a plane that is infinite in extent.

ALTERNATIVE STRATEGY

The well documented technique for rigorously applying vector isometric rotations to antenna patterns (5,6) and thereby correcting the measurements of misaligned antennas readily offers the possibility of producing antenna measurements based upon partial scans that are *not* coplanar. By rotating the antenna under test (AUT) about one or *more* spatial axes, that are not necessarily at a normal to the scan plane, and combining the partial scans it is possible to increase the "angle of validity" (7) of a planar measurement.

This introduces the possibility of constructing bespoke polyhedral measurement surfaces that enclose the antenna under test and that are designed to be more amenable for the derivation of wide-angle antenna performance from measurements made using existing, possibly smaller, planar near field measurement facilities.

This technique facilitates a reduction in the number of near field acquisition points, relative to a conventional planar measurement with an equal angle of validity, whilst retaining the mathematical and computational simplicity that is usually associated with the plane wave spectrum method and planar probe pattern correction.

The far field angular spectrum of the AUT is obtained by forming a superposition of the, two or more, successively obtained angular spectra for each of the individual partial planar acquisitions in the co-ordinate system associated with the radiator. The necessary isometric rotation is handled rigorously by expanding the plane wave spectrum on an irregular grid in the range system. This irregular space corresponds to a regular angular domain in the co-ordinate system associated with the radiator. After the transformation of the measured tangential field components, from the range polarisation basis into the antenna polarisation basis, the required isometric rotation is complete. Here, the rigorous application of alignment correction is not limited to that of the plane rectilinear co-ordinate system as these techniques are readily extended to the plane polar and plane bi-polar acquisition geometries.

VERIFICATION

In general, it is difficult to obtain closed form solutions for the electromagnetic field at a point in space from knowledge of the tangential electric or tangential magnetic fields over a closed surface for anything but the simplest cases. This is especially true when the closed surface is *not* coincident and synonymous with the aperture of the radiating structure, as is the case for near field antenna measurements. As such, recourse to alternative, typically numerical, methods for verification is unavoidable.

To this end the near field measurement geometry was simulated using the field equivalence principle to construct the surface of a partial plane, initially parallel with the x-y plane passing through the z=1m point. This plane was rotated by ±30° in azimuth about the origin of the antenna co-ordinate system to construct the field distribution plotted below.

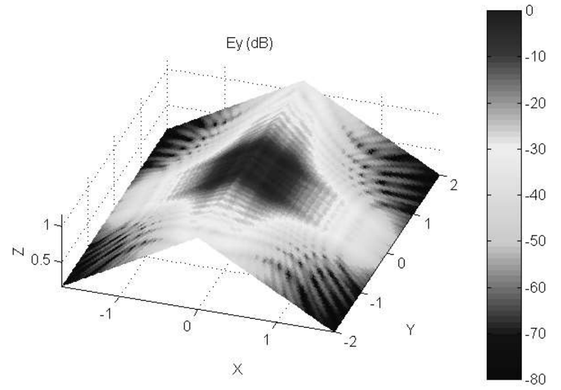

figure 1: Grey-scale plot of simulated near field power.

Figure 2 below is a far field plot comparing ideal far field data and equivalent data derived from the two rotated partial plane near field data as illustrated above.

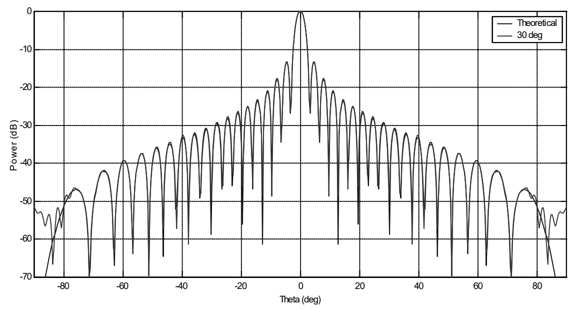

figure 2: Comparison of far field horizontal cuts of polyhedral transform and theoretical patterns.

The agreement between the respective cuts is good with differences only becoming apparent beyond ±80° where this is particularly apparent in the phase plot. Although the general agreement between the respective cuts is good, some differences are evident at very large angles. These differences have been found to result from the discontinuity encountered at the intersection of the two planes. Efforts to resolve this are ongoing.

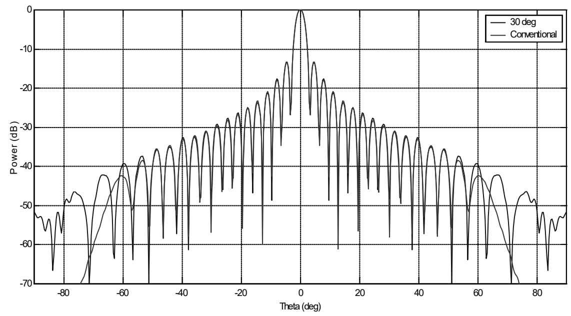

Figure 3: Comparison of far field horizontal cuts of polyhedral transform and conventional acqusition plane.

Allowing for the difficulties discussed above, Figure 3 illustrates the improvement in the ability to measure wide-angle antenna performance from approximately ±50° to ±80° with *no* change in the overall size of the acquisition surface.

STATISTICAL MEASURE OF ASSOCIATION

Clearly, the differences seen above are small. Hence, an objective assessment of the impact of differing processing techniques is difficult to assertion. The assessment of correlation between antenna patterns must reflect the anti-reductionist nature of the antenna pattern. This implies that only features that are global to the patterns are suitable for objective assessment, *i.e.* no part of the pattern should be excluded from the comparison process. Unfortunately, the objective statistical comparison of data sets produced in near field antenna measurements is complicated by two principal factors 1; The extensive dynamic range of the interval data 2; The data is defined relative to a reference signal.

The huge range of absolute values in the interval data complicates numerical techniques. This, in combination with the variation that can be expected in the data collected at different times or in different facilities, due to the lack of a common reference, leads to additional difficulties in the construction of measures of correlation (8).

Any proposed objective measure of correlation or association between data sets would be required to be, a single coefficient, independent of scaling or shift due to the differences in reference levels, insensitive to the large dynamic range of the data, normalised *i.e.* give correlation value ranging between 1 and –1, and finally, be symmetrical or commutative to the operation of correspondence. For any two interval data sets E_1 and E_2 where

$$E_1 = \left(E_1^i\right)_{i=1}^n \text{ and } E_2 = \left(E_2^i\right)_{i=1}^n$$

An accurate measure of correspondence between the data sets that satisfies the above requirements can be derived by concentrating on the ordinal aspects of the data. Let π_1^i be the rank of E_1^i in the E_1 data set and let π_2^i be the rank of E_2^i in the E_2 data set. A ranking is a permutation of integers that represents the relative ordering between interval values in a data set. If the ranks are not unique, *i.e.* two elements have the same value then the elements are ranked so that the relative spatial ordering between elements is preserved *i.e.* the first element has the smallest rank. The correlation between two rankings can be considered to constitute a measure of closeness, or distance between the two sets. A composition permutation S is defined such that s^i is the rank of the element in E_2 that corresponds to the element with rank i in E_1. Hence, for the case of a perfect positive correlation, $s = (1,2,3,\cdots n)$, where n is the number of elements in the set. The definition of a distance metric, to assess the distance between s and the identity permutation $u = (1,2,3,\cdots n)$, will result in a measure of the distance between π_1 and π_2. The distance vector d_m^i at each s^i is defined as the number of s^j where $j = 1,2,3,\cdots i$ which are greater than i which can be expressed as,

$$d_m^i = \sum_{j=1}^{i} J\left(s^j > i\right)$$

Where $J(B)$ is an indicator function defined as,

$$J(B) = \begin{cases} 1 & \text{when } B \text{ true} \\ 0 & \text{when } B \text{ false} \end{cases}$$

Here, d_m^i can be thought of as a measure, or estimate, of the number of elements that are out of order. If E_1 and E_2 were perfectly correlated then the distance measure will become a vector of zeros, *i.e.* $d_m(s,u) = (0,0,0,\cdots,0)$. The maximum value that any component of this distance vector can take is $\lfloor n/2 \rfloor$ which occurs for the case of a perfect negative correlation. Finally, a coefficient of correlation can be obtained from the vector of distance measures as,

$$k(I_1, I_2) = 1 - \frac{2\max_{i=1}^{n} d_m^i}{\lfloor n/2 \rfloor}$$

Here, if E_1 and E_2 are perfectly correlated then $(s = u)$ and $k = 1$. When E_1 and E_2 are perfectly negatively correlated then $k = -1$.

Previously, the validity of the alignment techniques that are crucial to the success of the auxiliary rotation scheme were assessed by acquiring an antenna at a variety of different orientations and comparing the agreement between the corrected far field results by inspection (9). This is repeated here, however the results are assessed with the aforementioned ordinal measure of association. The four data sets under consideration are:

Set 1. AUT nominally aligned to the range,

Set 2. AUT nominally aligned to the range but the scanning probe rotated around the range *z* axis,

Set 3. AUT misaligned in azimuth to the range,

Set 4. AUT grossly misaligned in azimuth, elevation and roll to the range.

The results from the comparison of these measurements can be found presented in the table and figure below.

Measurement Comparison	**k without Alignment**	**k with Alignment**

Point 1.	1-2	0.8854	0.9427
Point 2.	1-3	0.6756	0.9159
Point 3.	1-4	0.4598	0.9091
Point 4.	2-3	0.6774	0.9171
Point 5.	2-4	0.4476	0.9177
Point 6.	3-4	0.4091	0.9073

Table 1: Measure of association with & without alignment.

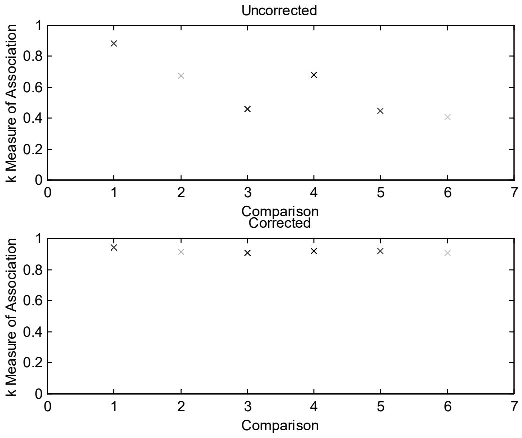

Figure 4: Plot of k with alignment correction and without alignment correction

Clearly, the application of the antenna to range alignment correction has significantly improved the degree of correlation between the patterns. However, the finite extent of the sampling interval is the principal limiting factor governing the applicability of the technique. This is illustrated by the smaller k values for those patterns with the largest rotation.

Despite the ordinal nature of this metric, the sensitivity of this technique is apparent from the discrimination of Sets 1 and 2 that previously have been found strongly associated. Furthermore, from the scale of the k values it is clear that those numerical instabilities that have previously been encountered when using interval techniques are avoided.

This paper recounts the progress of an ongoing research study. Consequently, several issues remain to be addressed and the future work is to include:

1. Develop the line charge method so that the electric, or magnetic, fields in the region of the discontinuity between partial scans can be removed.
2. Extend the transform to include four (or more) intersecting partial plane measurements to obtain data over the entire forward hemisphere.
3. Obtain experimental verification of the success of the auxiliary rotation technique. These results are to be assessed qualitatively by means of the inspection and quantitatively by means of statistical pattern recognition.
4. Extend the ordinal measure of association technique to include the assessment of cross polarisation and phase, and to investigate the effect of using differing distance metrics and correlation coefficients.
5. Investigate the use of a *categorical* measure of association.

CONCLUSIONS

Preliminary results attained from a novel alignment correction technique that has been extended to consider the derivation of far field parameters from a polyhedral measurement surface constructed from two or more partial scans that enclosed the radiator has been presented. These results have been assessed and are better able to obtain the wide-angle far field performance of an antenna under test than an *equivalently* sized conventional planar near filed measurement system.

The success of the necessary alignment correction technique has been assessed quantitatively with the use of an unconventional ordinal measure of association. Crucially, for the assessment of these results this metric provided a sensitive and stabile measure of similarity. The application of this measure for use as a penalty coefficient for use with genetic algorithms is clear.

REFERENCES

1. Johnson R.C., Ecker H.A., Hollis J.S.: “Determination of far field patterns from near field measurements”, Proc. of IEEE, vol. 61, pp. 1668-197, Dec. 1973.
2. S. Silver, “Microwave Antenna Theory and Design”, New York:McGraw-Hill, 1949, sec 3.8
3. C. A. Balanis, “Antenna Theory Analysis and Design”, John Wiley & Sons, 1997, Chapter 16, pp. 852.
4. McCormick J., Da. Silva E.: “The use of an auxiliary translation system in near field antenna measurements”. Proc. Int. Conf. on Antennas and Propagation, April 1997, Edinburgh, Vol. 1, pp. 1.90.
5. Gregson S.F., McCormick J.: “The application of non-rectilinear co-ordinate systems in the characterisation of mis-aligned space antennas”. Proc. AMTA, Monteray, Vol. 1.
6. Newell A.C., Hindman G.: “Antenna spherical coordinate systems and their application in combining different antenna orientations”. Proc. Int. Conf. On Antenna Measurements, May 1999, Noordwijk, Vol. 1, pp 41.
7. Yaghjian A.D.: “Upper-bound errors in far field parameters from planar near field measurements, Part 1: analysis”, National Bureau of Standards (US) Technical Note TN 667.1975.
8. D.N. Bhat, S.K. Nayar, “Ordinal Measures for Visual Correspondence”, Technical Report, CUCS-009-96, Columbia University Centre for Research in Intelligent Systems 1996.
9. S.F. Gregson, J. McCormick, “Image Classification as Applied to the Holographic Analysis of Mis-aligned Antennas”, ESA ESTEC Workshop an Antenna Measurements, 1999.