POLY-PLANAR NEAR-FIELD ANTENNA MEASURMENTS

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INTRODUCTION

Planar near-field measurement are used extensively for determining the performance of large high-gain antennas such as spacecraft arrays, where all the radiation occurs in the forward hemisphere centred on the antenna's aperture. 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 would 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 planar data sets that, in contrast to the single scan data set, fulfils 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 [1]. 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.

Techniques for rigorously applying vector isometric rotations to antenna patterns [2,3] and thereby correcting the measurements of misaligned antennas, readily offer the possibility of producing antenna measurements based upon partial scans that are *not* coplanar. By rotating the 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" of a planar measurement. The far field angular spectrum of the AUT is then 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. 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 conventional planar near-field measurement facilities. Indeed the method permits the measurement of larger antennas in a given facility and the technique facilitates a reduction in the number of near-field acquisition points, relative to a conventional planar measurement with an equal angle of validity. The method retains the mathematical and computational simplicity that is usually associated with the plane wave spectrum and planar probe pattern correction techniques associated with planar near to far field transformations.

TRI-SCAN CONFIGURATION

The tri-scan configuration is a practical candidate for a poly-planar system as the intersection between adjacent partial scans can be chosen to be away from regions of high field intensities. 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. This plane was rotated by ±30° in azimuth about the origin of the antenna co-ordinate system to construct the field distribution shown in figure 1. This constitutes a desirable arrangement where the intersections have been chosen to be across a region of space in which the field intensities are typically more than 30dB smaller than the largest signal.

Figure 2 contains a great circle cut of the equivalent far field vector pattern function compared with the idea (theoretical) pattern. Unfortunately, these results can be seen to be in error for very large angles *i.e.* those angles greater that 87° and stems from the discontinuity in the first derivative of the near field data across the intersection between the partial scans.

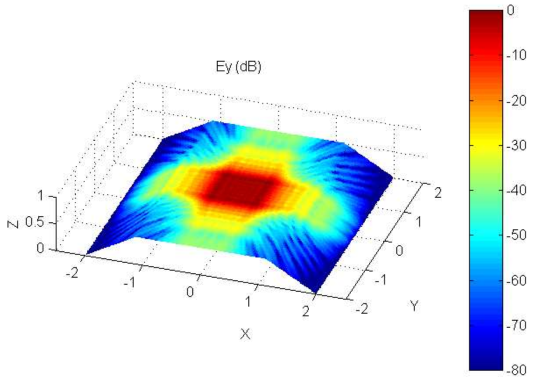

Figure 1 Pseudo-colour plot of simulated near field power for tr-scan configuration.

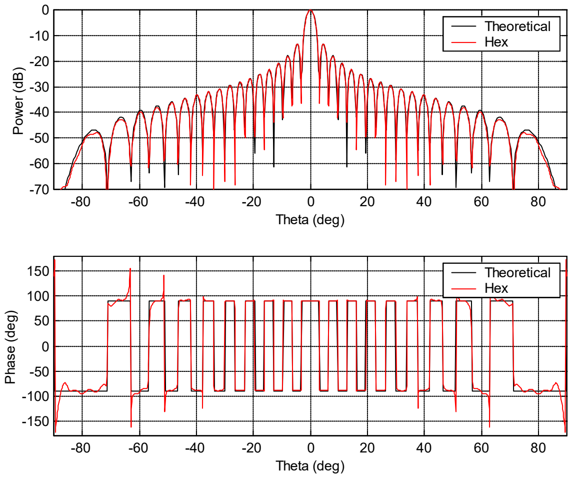

Figure 2 Comparison of far field horizontal cuts of polyhedraltransform and theoretical prediction.

However, it can be seen from figure 3 that the equivalent multipath level everywhere within the maximum look angle is low with the largest value being less than -60dB and the value being typically less than -70dB over the majority of the forward hemisphere which is approaching the practical noise floor of a typical planar facility.

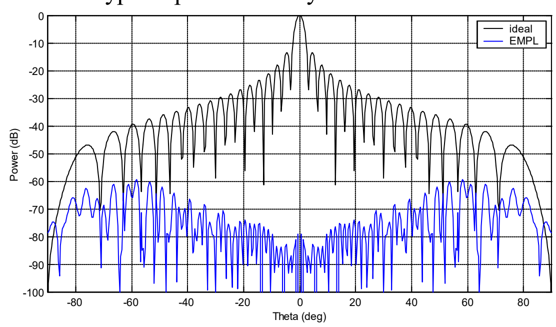

Figure 3 Comparison of far field horizontal cuts of polyhedral transform and theoretical prediction

The extent of the differences between the respective far field patterns can be quantified with the evaluation of the coefficient of ordinal correspondence *k*, details of which can be found in [4]. Table 1 below contains values of *k* that correspond to a conventional planar configuration, a bi-scan auxiliary rotation scheme (two plains inclined at ±30° and where the intersection is through the middle of the antennas peak field) and the modified tri-scan auxiliary rotation scheme.

Measurement	***k***
Conventional planar measurement	0.6372
Bi-scan auxiliary rotation scheme	0.5333
Tri-scan auxiliar rotation scheme	0.8088

Table 1 Comparison k-values from various measurement configurations.

The conventional planar measurement can be though of as constituting the benchmark by which other novel schemes can be compared. The imperfect *k* value reflects the degradation of the far field pattern that inevitably results from the introduction of spectral leakage caused by truncation of the near field data set. Although the bi-scan configuration successfully increases the ability of a given facility to determine wide-out antenna performance, additional errors are introduced that result from the intersection of the partial scans. Clearly the tri-scan scheme can be seen to offer results that constitute an overall *improvement* to those supplied by conventional planar techniques.

PENTHEDRAL-SCAN CONFIGURATION

The tri-scan scheme addresses the problem of obtaining wide-out azimuthal performance, but does not address the problem in the elevation plane. This can be resolved by rolling the antenna under test (AUT) through ±90° about its mechanical boresight and repeating the measurement. This would not be suitable for all antennas and alternatively the AUT can be "nodded" in elevation, then permitting data to be sampled over the surface of two additional planes. Data resulting from a simulation of this arrangement can be seen presented in Figure 4 below with the four *side planes* at 30° to the *top plane*.

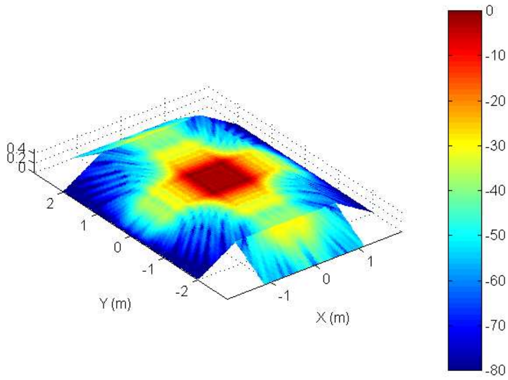

Figure 4 Plot of simulated penthedral near field data.

Unfortunately, the initial results were found disappointing for this measurement configuration. This is due to the lack of polarisation discontinuity of the x-polarised tri-scan system of figure 3, were as the two additional planes of figure 4 exhibit such a discontinuity. The source of this error can be traced to the incorrect determination of the field component normal to the scan plane. This field component is not sampled during an acquisition and is derived from the plane wave condition ($\underline{k} \cdot \underline{E} = 0$) that applies rigorously in the far field. Thus,

$$E_n = -\frac{\underline{k_t} \cdot \underline{E_t}}{k_n} \quad (1)$$

Where, E_n is the electric field component at a normal to the measurement plane, k_n is the component of the propagation vector that is tangential to the measurement plane. Similarly, E_t is the component of the electric field vector that is tangential to the measurement plane.

If however, the sampled data set is truncated, the reconstructed normal field component will be in error. Clearly, this is the case here. Furthermore, this field component is required before the partial data sets can be combined, as the principal of superposition requires that each component be resolved onto the same polarisation basis. These difficulties can be resolved if the normal field component is sought over the surface of each partial plane. All three orthogonal field components can then be transformed to the far field whereupon the partial data sets can be combined in the usual way. Thus, the normal field component over the partial scan plane can be expressed mathematically as,

$$E_z(x,y) = -\Im^{-1}\left\{\frac{k_x \Im\{E_x(x,y)\} + k_y \Im\{E_y(x,y)\}}{k_z}\right\}$$

(2)

Where $\Im$ represents the 2D Fourier transform of the near-field on a plane and $\Im^{-1}$ its inverse. Using the simulator the normal field component was obtained from the tangential components results from this comparison can be found in figure 5a.

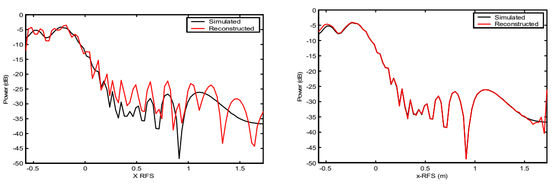

Figure 5 Plot of simulated and reconstructed normal field component without (a)and with (b) windowing

The spurious high frequency ripple that is present in the reconstructed normal field component can be removed by windowing the tangential field components before transforming to the angular spectrum. The "convoluted" normal spectral component can be obtained directly from (2) whereupon it can be inverse transformed to obtain the "windowed" normal field component. The windowing function can then be divided out to obtain reliable results such as those presented in figure 5b.

Various windowing functions have been tried however of those tried the best results have been obtained by utilising a Hanning *i.e.* a $\cos^2$, windowing function. At the extremities, this technique gradually becomes susceptible to noise and at the perimeter suffers from a divide by zero error. This can be overcome by over scanning the data where two planes join. Figure 6 below shows a far field co-polar azimuth cut for a representative tri-scan auxiliary rotation configuration for a 0, 5, 10, 15 and 20 column over scan configuration.

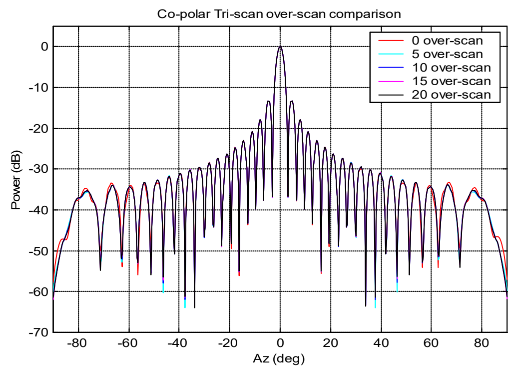

Figure 6 Comparison of far field horizontal cuts of polyhedral transform for various degrees of over scan.

Clearly, the over scan configurations improve the quality of the results obtained, this is most observable at wide angles however, an over scan of greater than five columns appears to offer limited improvement. The **k** value corresponding to that of Table 1 using 5 column overscan is ?????.

Inspecting the degree of agreement for the penthedral scan of figure 4 is now found to be encouraging with differences only becoming apparent at the –70dB level or for large polar angle. Table 2 below further illustrates the degree of success of this technique as it contains values of k that correspond to a conventional planar configuration and the penthedral auxiliary rotation scheme.

Measurement	*k*
Conventional planar measurement	0.6372
Penthedral-scan auxiliary rotation scheme	0.8154

Table 2 Comparison k-values for penthedral case.

This technique is particularly applicable for instruments with a rectangular aperture plane as little power is delivered to inter-cardinal regions. For circularly symmetrical instruments, further work is required.

EXPERIMENTAL VERIFICATION

A validation campaign to verify the following activites was undertaken:

- antenna under test (AUT)-range alignment corrections
- resolution of co-polar and cross polar against specified boresight
- probe pattern correction, probe orientation correction
- pattern normalisation
- pattern power integration
- stable transform gain

Auxiliary rotation partial scan schemes rely upon the ability to rotate a given instrument through arbitrary but known azimuth, and, or elevation angle. For the sake of mechanical simplicity, it was decided that only the azimuth auxiliary rotation system would be attempted. The AUT was mounted on a pin aligned jig that permited accurate step azimuth rotation of the AUT by ±15* and ±30° from boresight. The AUT used was a slotted waveguide array having a circular aperture of diameter ?? and operating at 9GHz, figure 7.

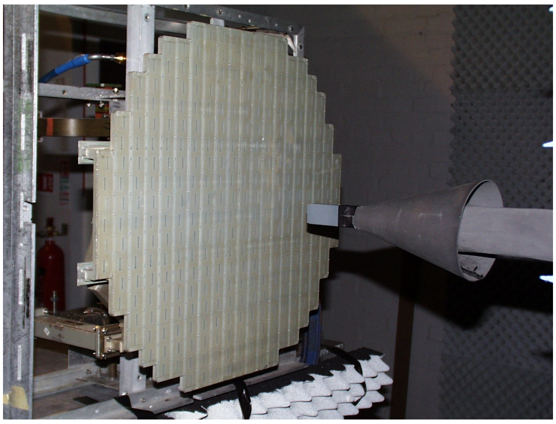

Figure 7 Picture of slotted waveguide array being scanned by a x-band rectangular waveguide probe.

Unfortunately, the auxiliary translation tests have revealed that in the presence of noise, a five columns over scan may not prove sufficient to obtain good results from an auxiliary rotation measurement configuration. Thus, it is envisaged that a second measurement campaign will be required to reacquire the AUT utilising differing degrees of over scanning. Initial resullts using 30 columns of overscan on the side planes and 25 columns on the centre plane are shown in figure 8. (the CATR pattern is not the same as in fig 9 of nov 01 progress report??. Can you also add the conventional PNFS result of this figure to the result below. The CATR results may well be wrong paricularly out at 60 to 90 degrees so it may be better to compare with conventional PNFS. Whats the EMPL between result below and the conventional PNFS?)

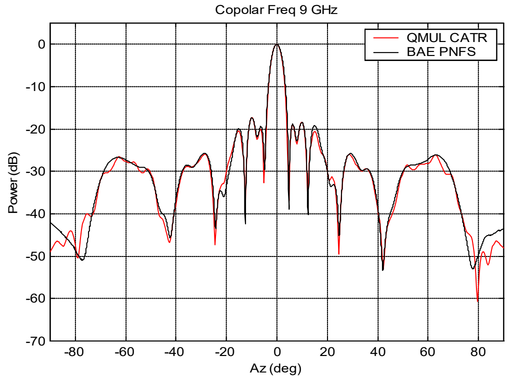

Figure 8 Comparison of tri-scan measured antenna pattern with that measured in a CATR and a conventional planar near-field system

CONCLUSIONS

A novel poly-planar near-field measurement system has been reported and the principle of operation verified using software simulation and experimental results. Development of the simulator to add in noise and random position errors is currently underway, as are addional measurements employing various degress of overscanning on each plane.

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