THE APPLICATION OF NON-RECTILINEAR CO-ORDINATE SYSTEMS IN THE CHARACTERISATION OF MIS-ALIGNED SPACE ANTENNAS

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Abstract

Traditional measurement methods assume that very accurate antenna to range alignment of the antenna under test (AUT) is convenient or possible. It has recently been shown that the use of non-rectilinear co-ordinate systems are of particular use for the purpose of correcting antenna to range misalignment.

Additionally, this misalignment correction can be used to construct an extended composite measurement plane from a series of mis-aligned scans that themselves can be considered as constituting a polyhedral measurement surface.

This paper describes the additional processing that is required to yield corrected near and far field data from an acquisition of a mis-aligned AUT. This technique is then illustrated with example results. The agreement of the corrected results is determined via the application of image classification techniques which correlate antenna patterns in a reduced vector pattern space in terms of their overall global features.

Keywords: ***Antenna, Measurement, Mis-aligned, Holographic, Image Classification.***

1. Introduction

The normal aim of a range measurement process is to characterise the radiation pattern of the AUT at a very great, or infinite, distance with reference to an angular or other co-ordinate system defined with respect to the mechanical interface. This data can then be utilised to establish the extent to which the instrument fulfils its requirements. The angular accuracy required is usually in the order of ±0.02°, particularly where the antenna is to be mounted on a spacecraft intended for low Earth, or geo-stationary orbit.

Typically, the intention of an antenna range test is to compare the instruments measured performance with that of a theoretical prediction or other similar criteria. An additional objective is to identify defective or incorrectly adjusted radiating elements in an array antenna.

The technique of microwave holographic metrology (MHM) is instantly recognisable as being especially well suited to such applications since it can be used to reconstruct the AUT's vector aperture illumination function. However, in general such holographic techniques are extremely sensitive to inaccuracies in the measurement technique. These inaccuracies are not limited only to uncertainty in the acquired data, but also include errors associated with truncation of the measurement data set.

The effects associated with sampling over a plane of limited spatial extent can be overcome via the construction of a combined data set. Such a data set is constructed from data acquired in a series of separate partial scans, [1,2]. In addition to the antenna to range alignment, the relative alignment between each partial scan must be known with the same degree of precision as that of the sampling grid over which the measurement itself is made.

2. Measurement Methodology

If an instrument is characterised whilst its axes are not perfectly aligned to those associated with the range, a non-rectilinear correction must be applied to the data set so that range independent predictions can be made.

For the case of the planar near field to far field transformation the application of alignment correction data is handled rigorously by expanding the plane wave spectrum (PWS) on an irregular grid in the range system. This irregular space corresponds to a regular angular domain in the antenna mechanical system. With the transformation of the measured Cartesian field components from the range polarisation basis into the antenna polarisation basis the required isometric rotation is completed.

The scanning probe can be thought of as a device that spatially filters the fields received from different parts of the AUT. In a planar range, the effects include something similar to a direct multiplication of the far field probe pattern with the far field antenna pattern. This can be seen to be a direct result of the nature of the convolution theorem

[3] and can be visualised directly from the mechanical operation of the scanner.

It is not usually possible to neglect these effects in the planar range because of the large angles of validity required and the short measurement distance employed. Considerable care has been taken over which co-ordinate system, and which field components, the probe convolution is understood to have taken place in so that a rigorous de-convolution can be applied. This has been extended so that an arbitrary, but known, probe orientation can be accommodated within the transformation process.

The reconstruction of near field data over a plane in space, other than the measurement plane, is accomplished by the application of a differential phase change. This can be seen to be analogous to a defocusing of the far field image. Near field data can then be readily reconstructed via the application of a two-dimensional discrete inverse Fourier transform.

This reconstructed plane can be chosen to be located at any of an infinite number of planes that are in the region of space at, or in front of the instruments phase centre. It is when the fields are reconstructed at a plane that is coincident with the AUT's *"aperture plane"* that this process is commonly found to be of greatest utility.

3. Far Field Results

The results illustrated in Figure 1 below contain a direct comparison between the corrected results as obtained from an AUT that was characterised whilst being grossly miss-aligned in azimuth, elevation and roll to the range axis *(Set 4.)*, with those obtained when the AUT was nominally aligned to the range axis *(Set 1.)*.

A successful overlay of the transformed data would indicate that the alignment corrections do not contain mathematical errors. Figure 1 below illustrates the levels of accuracy that can be expected for the prediction of the far field from the different data sets and by inspection the correlation between the predicted patterns is good.

The patterns illustrated in Figure 1 comprise a data set that contains more than six and a half thousand complex data elements and any direct numerical comparison, to confirm their similarities, is complicated by the large quantities of data inherent in the measurement process. However, the comparison of such large data sets can be significantly simplified by the well-documented [4] techniques of statistical pattern recognition. This has the important advantage of reducing the dimensionality of the data set. Any additional analysis is then reduced to the problem of considering a single point on a *"feature"* plane.

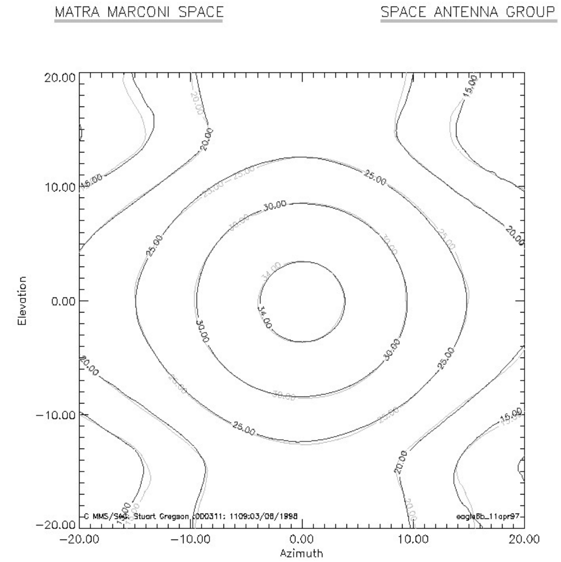


Figure 1.
Comparison of processed far field data from nominally aligned, and grossly misaligned measurements.

The figures below illustrate the difference between the results obtained from the comparison technique, when used on four different measurements, described below, when the data has been processed with (Figure 3) and without (Figure 2) the alignment correction. Please note the difference between the scales of the two plots.

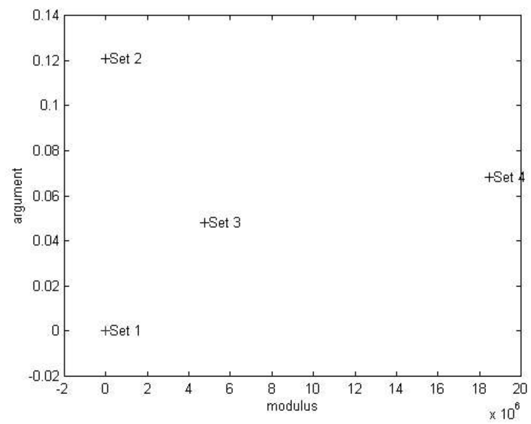


Figure 2.
Plot of far field antenna patterns plotted on a feature plane with no alignment correction applied.

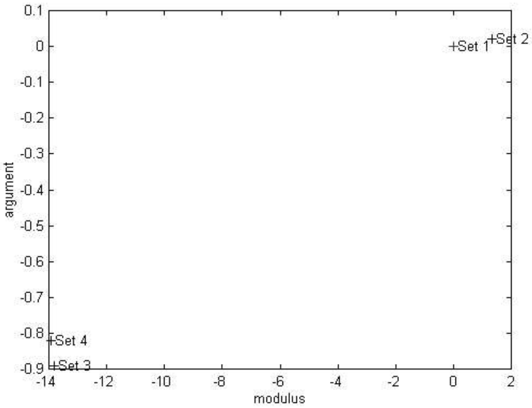


Figure 3.
Plot of far field antenna patterns plotted on a feature plane with alignment correction.

Where:

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,

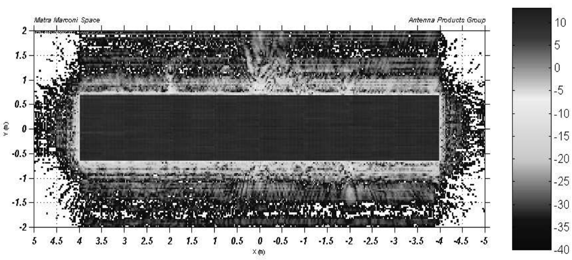
Set 3. AUT miss-aligned in azimuth to the range,

Set 4. AUT grossly miss-aligned in azimuth, elevation and roll to the range.

4. Near Field Results.

Alignment errors manifest themselves in different ways in each domain. If the issues associated with polarisation are ignored then an error in the antenna to range alignment will correspond to an angular displacement of the far field pattern. The same error will correspond to a change in the nature of the near-field pattern that is not in general characterised simply by a corresponding linear phase taper.

The patterns found below in Figure 4 contain the reconstructed aperture illumination function for a large synthetic aperture RADAR (SAR) antenna whilst operating in pulsed CW mode. Figure 5 contains a plot of the reconstructed elemental phase excitations plotted against the design specification.



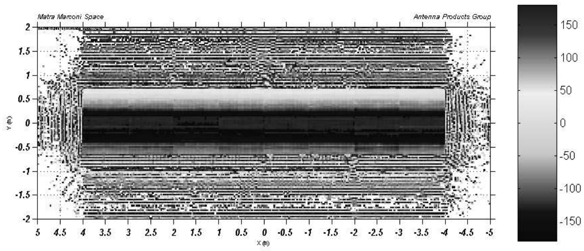


Figure 4.
Reconstructed aperture plane power(top), and phase (bottom) plots of a large SAR antenna.

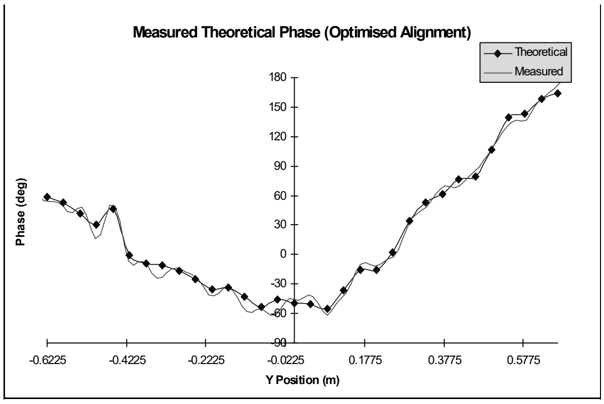


Figure 5.
Plot of reconstructed elemental excitations (phase) against design specification.

5. Auxiliary Rotation

The requirement that the data to be transformed is continuous over the sampling interval can be satisfied via the adoption of a number of different strategies. Clearly the simplest of these is to acquire the data over a scan plane which is of sufficient spatial extent to reduce the adverse effects associated with truncation to acceptable levels. If this is not possible, due to time constraints or limitations associated with the physical dimensions of the measurement system, the data may be windowed, [5]. This however can compromise the integrity of the function in the transform domain, although the extent to which this occurs may be reduced to an acceptable level over the particular angular range of interest.

The data to be transformed need not be the product of a single acquisition but rather the combination of a series of partial scans which when combined produce a data set which far more closely adheres to the prescribed boundary conditions. Typically this has been accomplished via combining data sets that have been acquired via a series of coplanar transforms, *e.g.* translations or rotations.

The process utilised in making measurements of misaligned antennas, as outlined above, offers the possibility of producing antenna measurements based upon partial scans that are not coplanar. Figure 6 below illustrates schematically that by rotating the AUT around an axis that is tangential to the measurement plane it is possible to increase the proportion of the forward hemisphere over which the measurement is made.

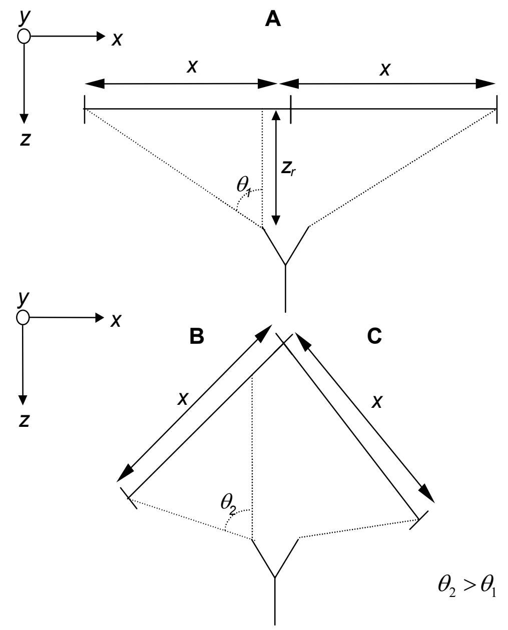


Figure 6.
Comparison of Auxiliary Translation and Auxiliary Rotation

Since the Fourier transform relates the spatial and angular domains in terms of angles being defined as rates of change of phase with respect to space, (PWS). Clearly then, the traditional methodology of combining data sets in the near field will be unsuccessful for the case where an angular variation between partial scans exists.

The fundamental requirement of the transform is that it allows the combination of the data in the partial scans such that specific vectors in each of the partial data sets represent a single vector in the combined data set.

In order that this technique could be investigated three near field data sets were constructed. These data sets corresponded to the measurement planes A, B and C as illustrated in Figure 6 above. Particular care was taken to ensure that the partial scans constituted a continuous piecewise measurement surface.

The results illustrated below in Figure 7 contain a comparison between the far field pattern obtained from a conventional transformation of data set A with a those derived from the combined data sets B and C.

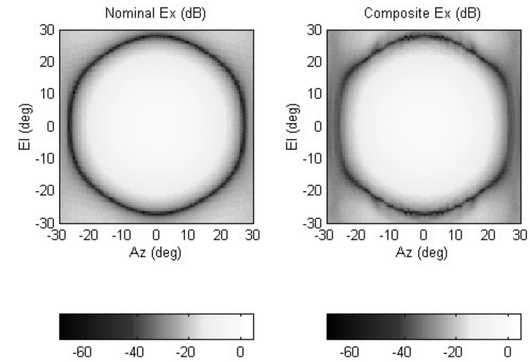


Figure 7.
Comparison of far field patterns obtained from a conventional measurement (left) and that from an auxilary rotation measurement (right).

Although the results illustrated above show a marked improvement over those obtained from the conventional transform with alignment correction, clearly the two far field patterns are not identical in the horizontal plane.

6. Discussion

Figure 2 and Figure 3 Illustrates the action of the application of the AUT to range alignment correction in feature space. In Figure 2 no realignment has been attempted and the distribution of points on the graph is indicative of the difference between the computed far field patterns. However, Figure 3 is consistent with the realignment process considerably improving the ability of the system to produce consistent results irrespective of the AUT's antenna to range alignment.

However, although the realignment process improves the quality of the results this process cannot completely overcome the misalignment problem. This can be seen from the plots since Set 3 and 4 are displaced from Set 1 and 2, although overall there is considerable improvement in the agreement between the results.

The results of this comparison confirm the accuracy of the measurement technique and highlight the errors introduced by the differences in truncation associated with the original measurement conditions.

The measured data sets, associated with the differently aligned antennas, in turn represent a partial knowledge of the field distribution over different finite planes in space. A consequence of the finite nature of these planes is that none of them contains sufficient data to compute precisely the far field pattern. The differences between these finite data sets will be manifest in differences in the computed patterns despite the realignment process.

Figure 4 contains pseudo colour plots of the reconstructed aperture plane amplitude *(top)* and phase *(bottom)* of a large pulsed SAR antenna. For the polarisation presented, the positions of the localised effects that are obtained immediately around the instruments aperture plane were found to coincide precisely with inactive mechanical equipment, *e.g.* hinges, telescopes and other mounting structures, and as such were attributed to coupling and diffraction. In addition to these effects, it is possible to observe, particularly in the phase plots, but also to a lesser extent in the amplitude plots, the junction between the eight individual columns of two tiles that constituted the instrument as a whole. Such discontinuities were expected and were later compensated for during the calibration process.

Figure 5 illustrates the degree of agreement obtained between the recovered elemental excitations for a vertical cut in the antenna aperture plane and the desired design specification. These results are encouraging since to achieve the degree of agreement shown, the near field results required only the application of a small in-plane displacement that corresponded to the physical displacement between the tip of the precision contacting probe, used to acquire the AUT to range alignment data, and the phase centre of the scanning probe. Clearly, the angular antenna to range alignment will not depend upon such a Cartesian offset within its derivation and as such this quantity is not usually required. When comparing these plots it is important to recognise that unlike the design specification (continuous line), the excitations produced by the active transmit and receive modules are quantised with a resolution of six bits $\approx 5.6°$.

From Figure 7 it can be seen that the new approach to the transform holds out the possibility of the highly accurate prediction of far fields from data acquired on a polyhedral surface. However, at this time it is also clear that the transformation process will need to be further developed and extended as the results do demonstrate that it is possible to address the first and second order truncation effects using this technique.

7. Conclusion

- The rigorous realignment process substantially increases the ability of the system to characterise antenna assemblies even in circumstances where gross misalignment is unavoidable or high degrees of angular precision are required.
- The rigorous holographic reconstruction of near field data from mis-aligned AUTs has been successfully demonstrated.
- The use of image classification has been shown to be of sufficient sensitivity to demonstrate the accuracy of these techniques and to highlight the impact of truncation on the measurement process.
- The finite extent of the sampling plane is the principal limiting factor governing the applicability of the technique. This is illustrated by the displacement of the points that are associated with specific patterns when plotted on a feature space plane. The singularity on this plane can be removed by redefining the co-ordinate system as polar.
- These limitations could be overcome by extending the data set from which the pattern is derived. This can be readily achieved by combining multiple data sets, and possibly to the extent of covering a full sphere with a set of polyhedrals.

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