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SINGLE CUT NEAR TO FAR-FIELD ANTENNA GAIN TRANSFORM

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Electromagnetic Measurements (ELECMEAS)

ABSTRACT

This following report describes a feasibility study undertaken to determine whether antenna radiation pattern measurements performed on a single ‘cut’ or plane in the near field region could be transformed to produce the far field radiation pattern of that plane with sufficient accuracy to be offered as a measurement service. Two approaches for performing this transformation are investigated based on prior literature. The first approach is based on a 2D near field to far field transformation using cylindrical wave expansions and probe correction coefficients. The second approach, also based on the cylindrical wave expansion, is for the specific case of an electrically long antenna array where one dimension of the antenna is significantly smaller than the other. Both approaches were applied to measured near-field radiation profiles of an X-band marine radar array. The results of these transformations were compared to the far field profiles calculated from the full two-dimensional set of measurements using the program SNIFTD. The single cut transformations were found to differ significantly from each other and the calculated far field pattern, thus the method has been determined to be unsuitable as a measurement service.

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CONTENTS

1 OVERVIEW OF MEASUREMENT SET-UP

The goal of the work presented here was to investigate the accuracy of single cut near to-far-field transformations of antenna radiation profiles with a view to offering this as a measurement service. Currently, antenna radiation patterns are measured in the near-field of the Antenna Under Test (AUT) in two-dimensions, θ and $\emptyset$, over the surface of a sphere with the AUT at its centre. These near-field measurements are then converted to a far-field radiation pattern using a commercially available software program, SNIFTD, based on the work of Hansen and Larsen[1]. This process, whilst it provides accurate far-field radiation pattern results, is time consuming as it requires many data points to be taken over the spherical surface of the scan and for the scan to be repeated with the probe antenna rotated by 90˚. For many antenna applications, knowledge of the radiation pattern of only a single plane is required. In these cases, it would be more efficient to be able to measure only the plane of interest, effectively taking a single cut through the spherical measurement.

The measurement set-up is shown in Fig.1, below. The probe antenna and AUT are mounted opposite one another in the measurement range, separated by a distance r. The AUT is mounted on two rotational stages that allow it to be scanned in both the polar (θ) and the azimuthal ($\emptyset$) direction. The measurements take place in an anechoic chamber to prevent environmental noise and reflections from the walls of the range from interfering with the measurement. Each radiation pattern measurement requires two scans of the AUT near-field, between scans the probe antenna is rotated by 90˚. For a single cut measurement, the AUT is scanned only in the θ-direction and the $\emptyset$ value is kept constant at 0˚/180˚.

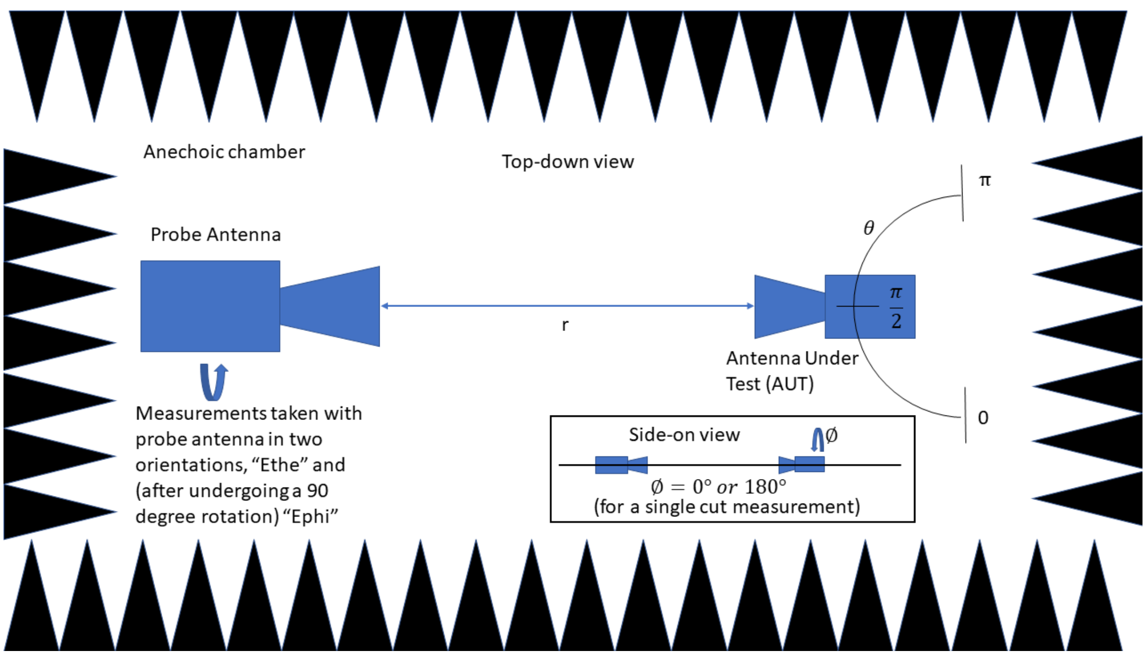

Fig.1: Shows the antenna radiation profile measurement set-up. The measurements are performed in an anechoic chamber. The probe antenna and AUT are separated by a distance, r. The AUT is mounted on two rotating stages to allow for measurements in both the $\emptyset$- and θ-directions. The probe antenna is mounted in a stationary position and is rotated by 90˚ for the second measurement.

2 NEAR TO FAR FIELD TRANSFORMATION THEORY

Single cut near-to-far-field transforms have been performed, with successful examples, in literature. These are based on a variety of different transformation techniques including: cylindrical wave expansion[3],[4],[5],[6], linear equivalent electric current[7], singular value optimisation[8] and 3D Green's function[9]. The single cut near-to-far-field transforms explored in this work are based on the cylindrical wave expansion (CWE) as these techniques have the same measurement requirements as the 2D spherical measurements taken in the NPL range already. Two different near-to-far-field transformations based on CWE have been explored here. The first, which includes the probe correction also used in the SNIFTD transformation, is effectively the same transformation as the 2D form but with a cylinder of infinitely small height. The second transformation is a special case of the CWE transformation for long antennas that have one dimension much smaller than the other. This transformation requires no probe correction.

2.1 SINGLE CUT CYLINDRICAL WAVE EXPANSION WITH PROBE CORRECTION.

This approach is based on the work of Leach et al[2] and Salmeron-Ruiz et al[3]. The Leach paper details a 2D transformation based on the cylindrical wave expansion of an electromagnetic field where the far-field pattern is obtained from near-field data measured over the surface of a cylinder surrounding the antenna. It has been shown previously that, in the near-field region, the probe antenna can affect the measurement itself. The Leach paper shows that this can be accounted for, if the complex amplitude weighting functions of the probe, when used as a transmitter, are known. These can be obtained from the far-field radiated by the probe. In the case of the measurements shown here, the weighting functions of the probe used are those of a hertzian dipole. The same weighting functions have been used in the SNIFTD program to produce the far-field reference patterns,

This near-to-far-field transformation can be performed on a single cut of data by considered it to be a cylinder of infinitely small height. In this case two measurements of the single cut are taken with the probe antenna in two orthogonal orientations. The equations governing this transformation are given below in Section 2.1.1.

The requirements of this transformation are as follows:

- Near-field single cut measurements must be taken with the probe antenna in two, orthogonal orientations.
- The probe correction coefficients must be known.

2.1.1 Relevant Equations

For a single cut measurement, the far field pattern is calculated from the equation below:

$$E(r \to \infty, \theta, \emptyset) = -2k_0 \sin\theta \sum_{n=-\infty}^{\infty} j^n \cdot (a_n \cdot \hat{\emptyset} + j \cdot b_n \cdot \hat{\theta}). e^{jn\emptyset},$$

where k_0 is the wavenumber, θ is the angle of the AUT and lies between 0˚ and 180˚, n is the number of data points, and $\hat{\emptyset}$ and $\hat{\theta}$ are the unit vectors in the $\emptyset$- and θ- directions. a_n and b_n are the Cylindrical Mode Coefficients (CMCs) and are calculated by:

$$a_n(h) = \frac{k^2}{\Lambda^2 \Delta n(h)} \left(I_n(h) \sum_{m=-\infty}^{\infty} d'_m(-h) H_{n+m}^{(2)}(\Lambda r_0) - I'_n(h) \sum_{m=-\infty}^{\infty} d_m(-h) H_{n+m}^{(2)}(\Lambda r_0) \right),$$

$$b_n(h) = \frac{k^2}{\Lambda^2 \Delta n(h)} \left(I_n'(h) \sum_{m=-\infty}^{\infty} c_m(-h) H_{n+m}^{(2)}(\Lambda r_0) - I_n(h) \sum_{m=-\infty}^{\infty} c_m'(-h) H_{n+m}^{(2)}(\Lambda r_0) \right),$$

where $m = 1$, as only a single cut of the data is being considered and d, c, d', c' are the probe correction coefficients. The Hankel function of the second kind, $H_{n+m}^{(2)}(\Lambda r_0)$, is calculated using the large asymptotic expansion:

$$H_n^{(2)}(\Lambda r) \sim j^n \left(\frac{2}{\pi \Lambda r} \right)^{\frac{1}{2}} e^{-j\Lambda r} e^{jn\theta},$$

where r is the distance between the probe antenna and the Antenna Under Test (AUT), $\Lambda = \sqrt{k^2 - h^2}$ and $h = k \cos(\theta)$. The integrals $I_n(h)$ and $I_n'(h)$ are calculated as follows:

$$I_n(\mathrm{h}) = \int_{-\pi}^{\pi} v(r_0, \theta) e^{-jn\theta} d\theta,$$

$$I'_n(\mathrm{h}) = \int_{-\pi}^{\pi} v'(r_0, \theta) e^{-jn\theta} d\theta,$$

where $v(r_0, \theta)$ and $v'(r_0, \theta)$ are the near field, single cut measurements taken with the probe antenna in two different (orthogonal) orientations. Finally, $\Delta n(h)$ is calculated by:

$$\Delta n(h) = \left(\sum_{m=-\infty}^{\infty} c_m(-h) H_{n+m}^{(2)}(\Lambda r_0) \right) \cdot \left(\sum_{m=-\infty}^{\infty} d_m'(-h) H_{n+m}^{(2)}(\Lambda r_0) \right) - \left(\sum_{m=-\infty}^{\infty} c_m'(-h) H_{n+m}^{(2)}(\Lambda r_0) \right) \cdot \left(\sum_{m=-\infty}^{\infty} d_m(-h) H_{n+m}^{(2)}(\Lambda r_0) \right)$$

2.2 SINGLE CUT CYLINDRICAL WAVE EXPANSION FOR LONG ANTENNAS

This approach is based on the work of Zhou et al[4] and Li et al[5] and is also based on the cylindrical wave expansion. It is concerned with the near-to-far-field transformation of a specific type of antenna; one which has one large dimension and one small. This approach uses the fact that the far-field conditions of the small dimension of the antenna are more easily satisfied than the long dimension. A minimum cylinder is constructed that is large enough to surround the whole AUT and satisfies the far-field condition of the smallest dimension of the antenna. The equations governing this near-to-far-field transformation are given is Section 2.2.1 below.

To perform this transformation, two requirements must be met:

- Near-field single cut measurements must be taken with the probe antenna in two, orthogonal orientations.
- The AUT must have one dimension much smaller than the other.

2.2.1 Relevant Equations

The far-field pattern for a single cut near-to-far-field transformation for an electrically long antenna is calculated from:

$$E_{\theta,\emptyset}(r, \theta, 0) = \frac{1}{\sqrt{r}} \sum_n C_n H_n^{(2)}(kr) e^{jn\theta},$$

where C_n is either of the CMCs, a_n and b_n and is calculated by:

$$C_n = \frac{\sqrt{r}}{2\pi H_n^{(2)}(kr)} \int_{-\pi}^{\pi} E_{\theta,\emptyset}(r,\theta,0) e^{-jn\theta} d\theta,$$

where E is the measured quasi-far-field profile. As $r \to \infty$:

$$H_n^{(2)}(kr) = j^n \left(\frac{2}{\pi kr}\right)^{\frac{1}{2}} e^{-jkr} e^{j\frac{\pi}{4}},$$

Omitting a constant, the far-field pattern is then given by:

$$F_{\theta,y}(\theta) = \sum_n C_n^{y,\theta} j^n e^{jn\theta}.$$

The co- and cross-polarisation far-field patterns can then be calculated by:

$$F_{co}(\Psi) = F_\theta \cos(\Psi) + F_y \sin(\Psi),$$

$$F_{cross}(\Psi) = F_\theta \sin(\Psi) - F_y \cos(\Psi),$$

where Ψ is the angle between the $\hat{\theta}$-polarisation and the co-polarisation.

3 TRANSFORMATION RESULTS

The transformations described in Section2 have been implemented in MATLAB and used to calculate the far field radiation pattern of an X-band marine radar array A complete set of two-dimensional measurements have been performed on this antenna at *r* = 3m (within the antenna near-field). These 2D measurements have undergone a separate near-to-far field transformation using the program SNIFTD and the calculated far-field has been used to compare with the single-cut transformations. A comparison between the near-field measurements and the far-field calculated with SNIFTD is given in Fig.2, below.

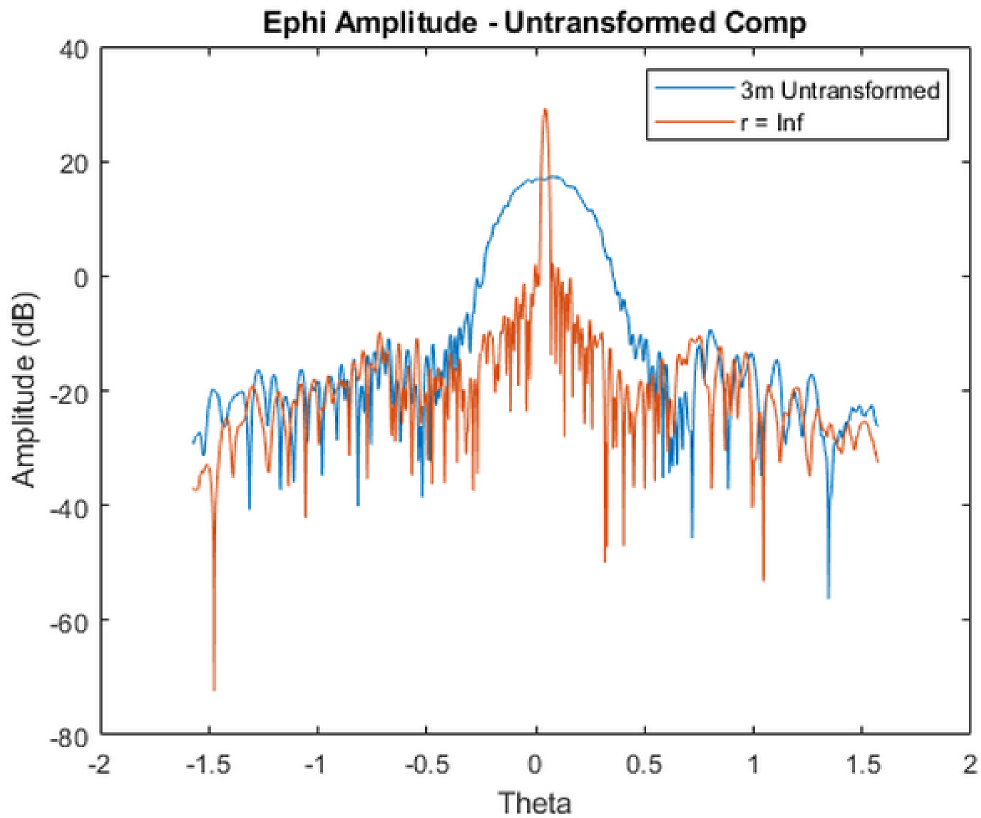

Fig.2: Shows a comparison between the measured near-field data at 3m (blue line) for a single cut taken at ∅ = 180˚ and the far-field for the same plane as calculated by SNIFTD (orange line).

3.1 SINGLE CUT CWE WITH PROBE CORRECTION

The same near-field data shown in Fig.2 was input into a MATLAB program written to carry out the near-to-far-field transformation detailed in Section.2.1. The results of this transformation can be seen in Fig.3.

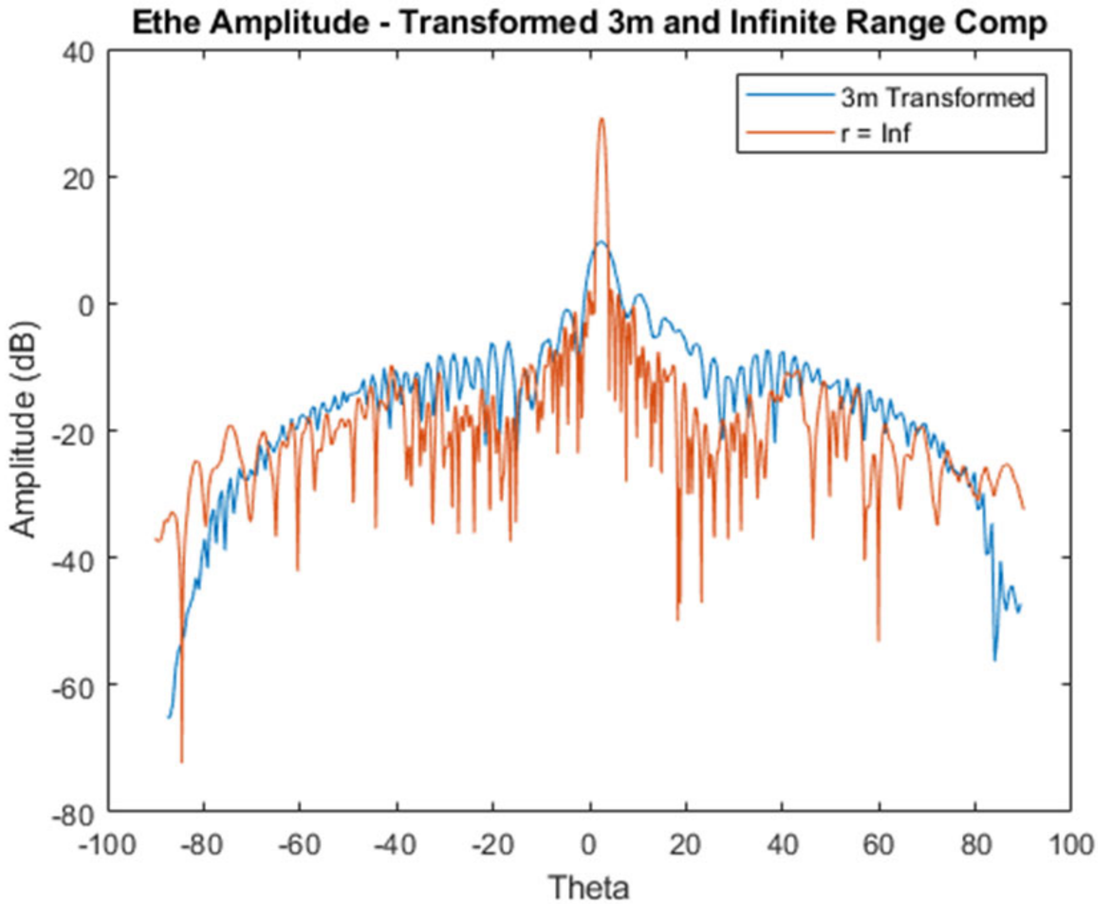

Fig.3: Shows a comparison between the far-field pattern calculated using the single cut CWE with probe correction transformation (blue line) and the far-field pattern calculated using SNIFTD (orange line).

3.2 **SINGLE CUT CWE FOR ELECTRICALLY LONG ANTENNAS**

The far-field pattern has also been calculated using a near-to-far-field transformation specifically for electrically long antennas, described in Section.2.2. The results of this transformation are seen in Fig.4.

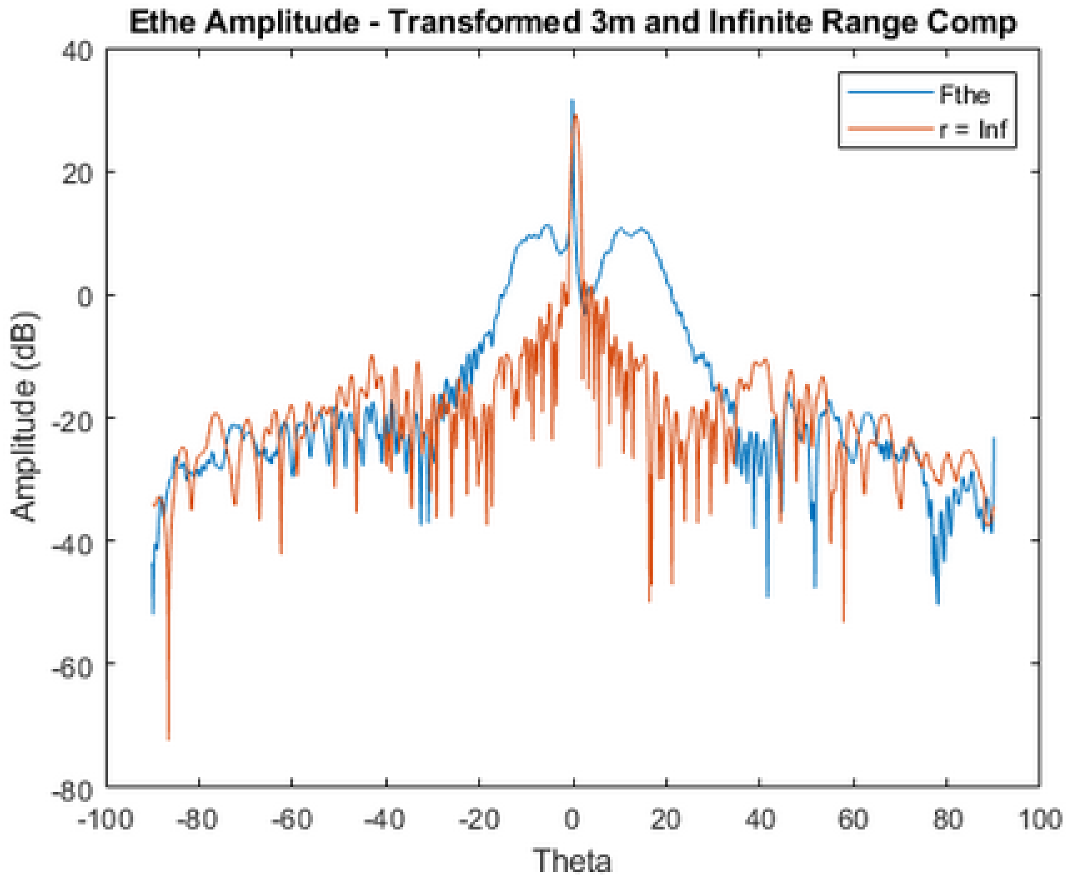

Fig.4: Shows a comparison of the far-field pattern calculated using the single cut transformation for electrically long antennas (blue line) and the far-field pattern calculated using SNIFTD (orange line).

3.3 COMPARISION OF TRANSFORMATION RESULTS WITH AN X-BAND MARINE RADAR ARRAY PASS LINE

The data used in this report to test the single cut near-to-far-field transformations is from an X-band marine radar array. The radiation pattern from these antennas must fall within a strict pass template given by the radar array manufacturer. The results of the single cut transformations have been plotted here, in Fig.5 and Fig.6, against this template.

Fig.5 shows the result of the CWE with probe correction transformation compared to the X-band marine radar array pass line (in yellow) with the SNIFTD far-field pattern also plotted for reference. Whilst the calculated transformation only just falls outside the pass line either side of the main peak, the failure of the transformation to reproduce the true characteristic of the peak means that this transformation could not be used with confidence to test the performance of these antennas.

The comparison of the CWE for the electrically long antenna transformation and the X-band marine radar array pass line is shown in Fig.6 along with the SNIFTD far-field pattern for reference. The main peak of the far-field pattern produced by this transformation falls within the pass line and reproduces the height but not the width of the main peak as calculated by SNIFTD. However, this transformation produces wide side lobes either side of the main peak which fall well outside of the pass line, making it unsuitable for use in testing these antennas.

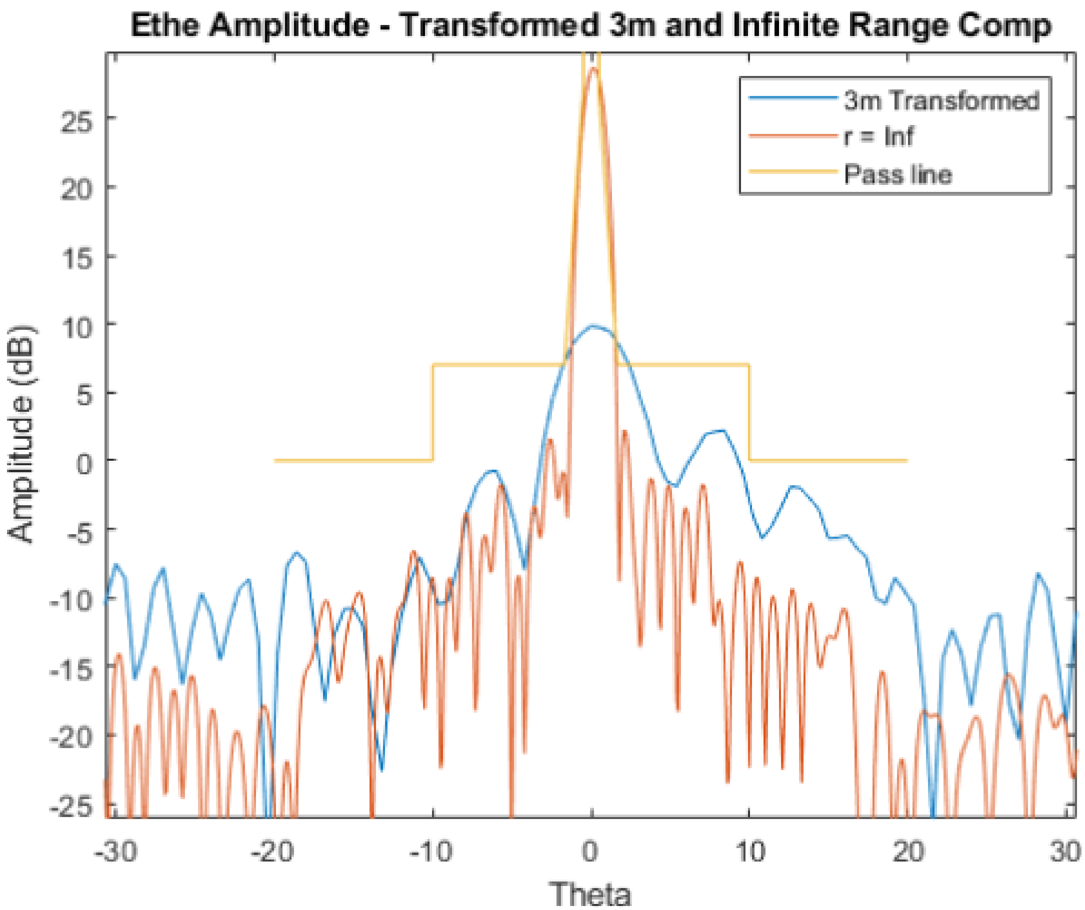

Fig.5: Shows the far-field pattern as calculated by the single cut CWE with probe correction transformation (blue) and SNIFTD (orange) compared to the X-band marine radar array pass line (yellow).

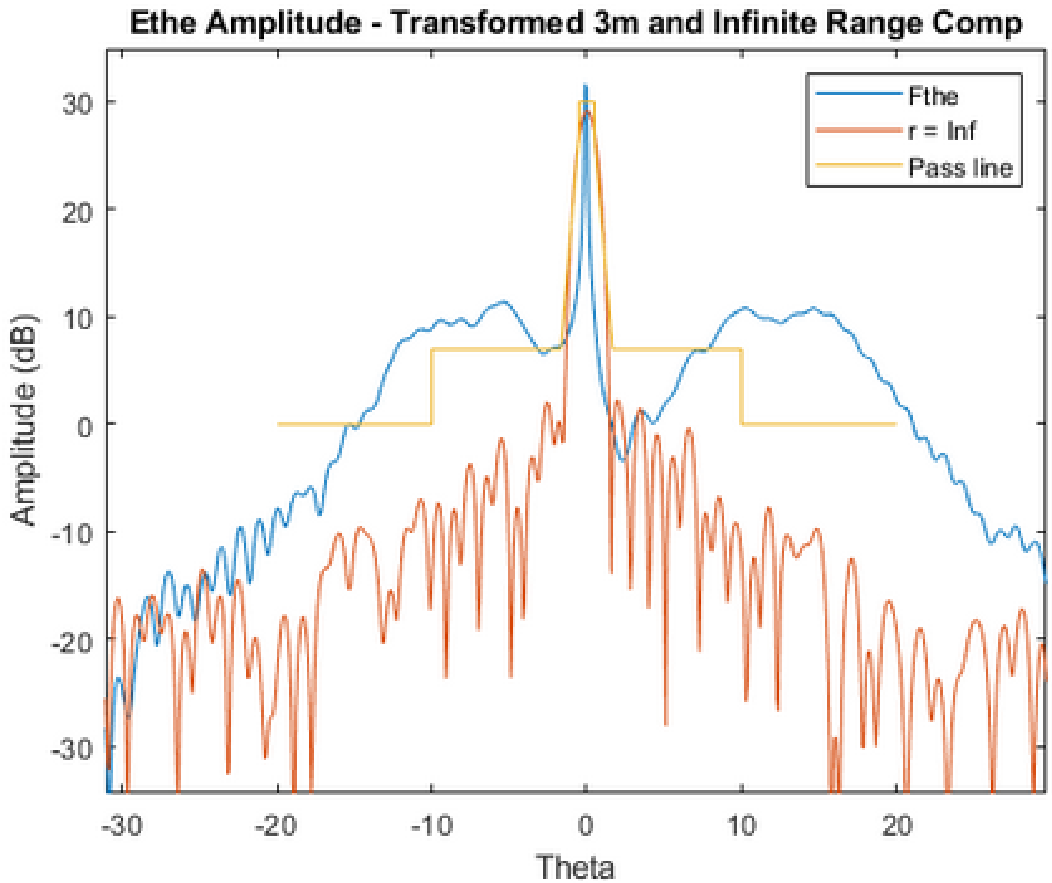

Fig.6: Shows the far-field pattern as calculated by the single cut CWE for electrically long antennas transformation (blue) and SNIFTD (orange) compared to the X-band marine radar array pass line (yellow).

4 CONCLUSIONS

A single cut near-to-far-field transformation of near field data from an X-band marine radar arrayhas been implemented two ways. First, using an approach based on the cylindrical wave expansion that includes correction coefficients for the probe antenna used in the measurements. The second approach, also based on the cylindrical wave expansion, is a special case for long antennas where one dimension is significantly smaller than the other. In both cases the results of the single near-to-far field transformation differ significantly from the 2D near-to-far-field transformation carried out using SNIFTD. The first single cut approach fails to reproduce the characteristic height and narrow width of the main peak whilst the second approach reproduces the height but not the width of the main peak and results in large side lobes not seen in the SNIFTD transformation.

The results of the single cut transformations have also been compared to a pass template used by the radar array manufacturer to determine whether the radiation pattern of an antenna falls within acceptable limits. In particular, whether any side lobes the radiation pattern has are sufficiently low. Only the second approach results in a pattern profile which has a clearly defined peak, but the large side lobes fall far outside of the pass line and do not occur in the SNIFTD result. The second approach is therefore not appropriate for pass/fail testing of the radar arrays.

In conclusion, neither of the single cut near-to-far-field transformations attempted here are suitable to be offered either as a measurement service or to evaluate pattern profile versus a pass template.

5 ACKNOWLEDGEMENTS

Thank you to Zhengrong Tian for providing the far field patterns for the X-band marine radar array used as a reference here and her help understanding the SNIFTD program used to produce them.

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