EXPLORATION OF THE FEASIBILITY OF ADAPTIVE SPHERICAL NEAR-FIELD ANTENNA MEASUREMENTS – PART II

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ABSTRACT

The use of pre-conditioning interpolation schemes, as a possible means of enhancing the performance of previously introduced adaptive acquisition algorithms for spherical near-field (SNF) test time reduction, is evaluated. Investigations have been carried out to establish whether the adaptive SNF approach is suited to test engineering practice are reported. The pre-conditioning method involving the acquisition of two orthogonal polar cuts on the near-field sphere and the separate linear interpolation of two complex spherical components of the NF data is shown to be the preferred scheme. This method is evaluated for three different antennas using specific acquisition rules, and decision functions related to directivity, amplitude error, and side lobe level.

1. Introduction

An adaptive acquisition algorithm for spherical near-field (SNF) test time reduction was proposed in [1]. It is based on the premise that near-field to far-field (NF-FF) transformation time is small compared to data acquisition time, so that such computations can be done repeatedly while data is being acquired. This allows the use of the transformed FF data to continuously compute and monitor pre-defined decision functions (formed from the antenna-under-test (AUT) specifications) while data is being acquired. The idea is to effectively allow the probe to follow a directed path under control of an acquisition rule, so that the sampled NF data points constitute an acquisition map on the measurement sphere. SNF data acquisition is then terminated based on decision function values, the intention being that the smallest amount of data needed to ensure accurate determination of the AUT performance measures will be acquired. The feasibility of the approach was demonstrated using actual NF data for several antennas, using various decision functions and acquisition rules.

This paper is a continuation of the work reported in [1] and will report on tests that have been carried out to establish suitability of the approach to test engineering practice. In addition, a pre-conditioning concept is introduced that obviates the need to assume zero value NF start values. Different pre-conditioning interpolation schemes will be compared as to their influence on the adaptive SNF process.

2. Interpolation and Pre-Conditioning

In [1] the start values of all NF data points were assumed to be zero, implying that fields on the measurement sphere were zero everywhere. These values were then replaced by actual measured data as the acquisition proceeded. At any stage only a portion of the fields on the measurement sphere would have been sampled. This introduced a significant and ever changing truncation effect. In order to soften this transition (that is, avoid the truncation effect) an interpolation method was implemented for adaptive planar near-field (PNF) systems in [2], as opposed to adaptive SNF, and referred to as pre-conditioning. Here, this pre-conditioning concept is applied to the SNF case. The idea is to use an approximation of the NF data as a starting point instead of an empty NF array, thus avoiding the use of zero field values entirely. Two or more cuts of NF data are acquired before the adaptive SNF method is initiated and the entries in the NF array are set to the values obtained by interpolation of the data points acquired.

Three possible orthogonal cuts on the sphere are considered; the first two cuts are referred to as polar cuts while the third is referred to as an equatorial cut:

- Cut $\varphi = 0°$, with θ from 0° to 360°
- Cut $\varphi = 90°$, with θ from 0° to 360°
- Cut $\theta = 90°$, with φ from 0° to 360°

Three different interpolation schemes have been investigated:

Method #1: Two orthogonal polar cuts are acquired on the near-field sphere. The two complex spherical components of the NF data are separately interpolated linearly, even though it is known that the spherical coordinate unit vectors are not constant.

Method #2: Two orthogonal polar cuts are acquired on the near-field sphere. The three complex rectangular components of the NF data are separately interpolated linearly. These are reconverted to spherical components and the remnant radial component is discarded.

Method #3: Two orthogonal polar cuts are acquired on the near-field sphere. This NF data is used, with the field values at all the not-yet-acquired NF data points set to zero, in order to determine a set of spherical wave coefficients. Only those coefficients needed to properly determine the FF from this incomplete NF data set are found. These coefficients are used in the spherical wave expansion to determine the NF values at points on the measurement sphere that do not fall on the two orthogonal cuts actually acquired. In the above process the size of the grid is set by the maximum radial extent (MRE) of the AUT.

Pre-conditioning using these three interpolation schemes was studied by using measured NF data for a wireless base station antenna. By comparing measured NF values and comparing that to NF values obtained using the pre-conditioning schemes, one obtains a measure of success of the pre-conditioning. These results are shown as an amplitude error in Fig.1 and Fig.2 for Methods #1 and #2, respectively. The amplitude error quantity shown is the difference between the magnitudes of the actual and interpolated NF data set (at each point), normalized by the actual measured value.

In Fig 1 and Fig 2 below there is no amplitude error when φ is fixed to 0° and 90° (the error is $-\infty$ dB); this is expected since these two cuts are actual acquired values needed to carry out the interpolation to points elsewhere. As seen in Fig.3, both methods approximate the actual fields reasonably well in the region of the near-field sphere where the largest amplitudes ("hot spots") are located. In this figure, the interpolated fields are computed using Method #1 - similar pattern is found using Method #2.

Even though the two methods appear to do equally well, the application of these interpolation methods has been examined on some NF data and it was determined that Method #2 introduces an inherent error due to the radial component being discarded after the interpolation process. This is not so for Method #1. The error present within Method #2 gives less confidence to the validity of the interpolated fields using this method.

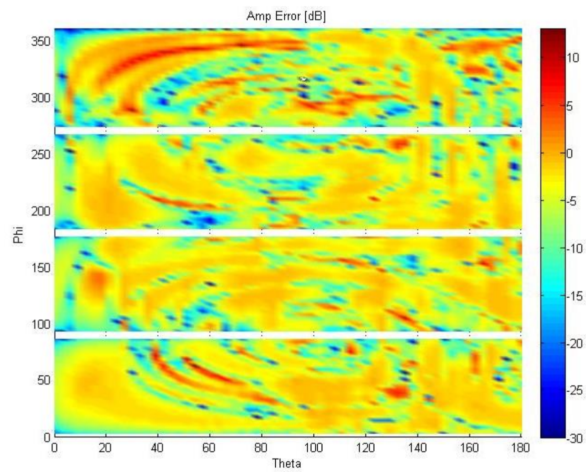

Fig.1: Amplitude error of the pre-conditioned NF data values (over the measurement sphere) using interpolation Method #1 for a base station antenna.

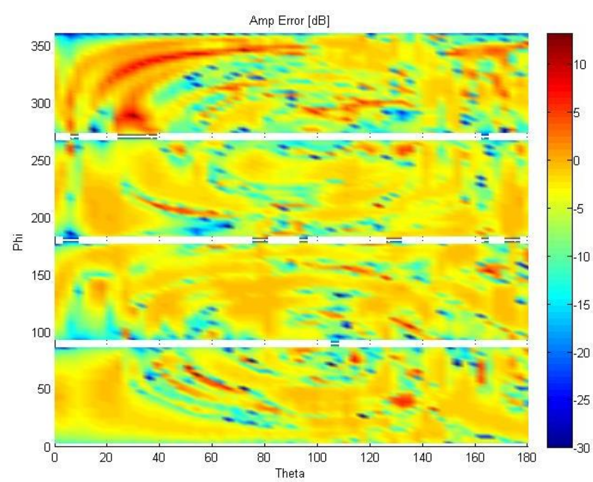

Fig.2: Amplitude error of the pre-conditioned NF data values (over the measurement sphere) using interpolation Method #2 for a base station antenna.

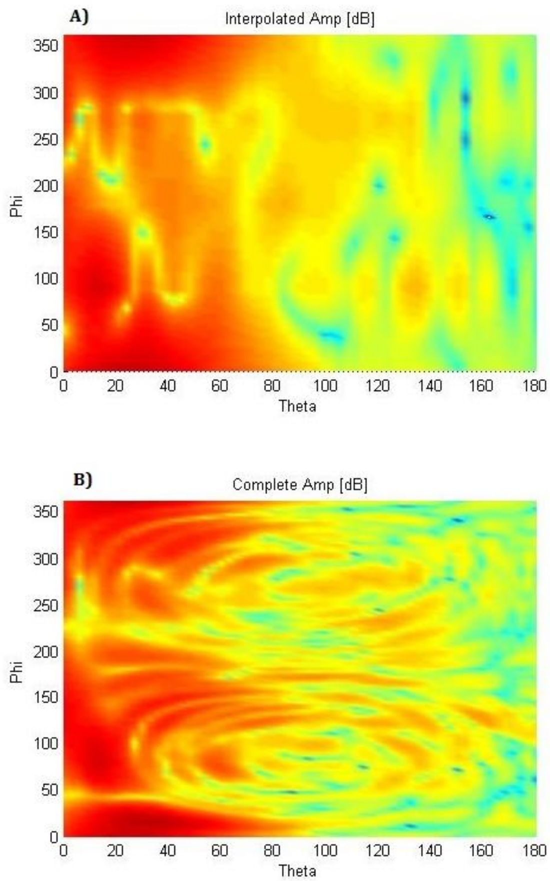

Fig.3: A) Interpolated θ-polarized NF amplitude using pre-conditioning Method #1, B) Amplitude of the acquired θ-polarized NF for a base station antenna.

Fig.4 provides the amplitude error for the interpolation performance of Method #3. The quality of interpolation is poor in comparison to the results observed in Figs 1 and 2. While the fields are much smoother, with no abrupt changes in value over the near-field sphere, the overall performance is not as effective as the other two methods. This interpolation scheme was therefore not investigated further.

In order to be able to discriminate more carefully between the pre-conditioning schemes Method #1 and Method #2, the adaptive SNF method was applied to a fan beam antenna with and without pre-conditioning. The evolution of the acquisition for this AUT is shown in Fig.5, with the maximum directivity provided as a function of the percentage of the acquired measurement sphere. In the light of the limitation mentioned previously for Method #2, Method #1 is the preferred interpolation scheme and is discussed further below, even though Method #2 converges faster in this particular case.

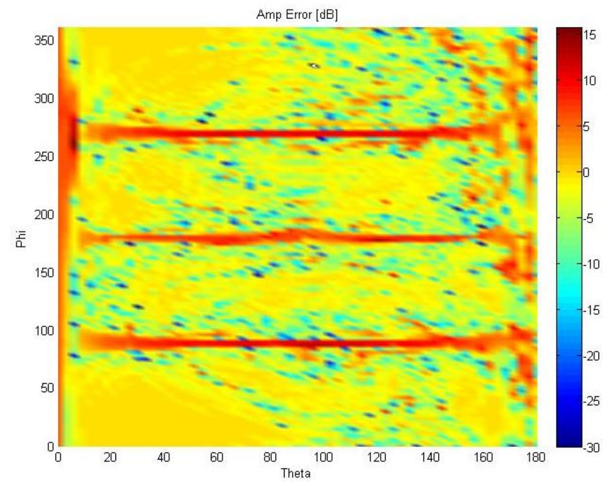

Fig.4: Amplitude error of the pre-conditioned NF data values (over the measurement sphere) using interpolation Method #3 for a base station antenna.

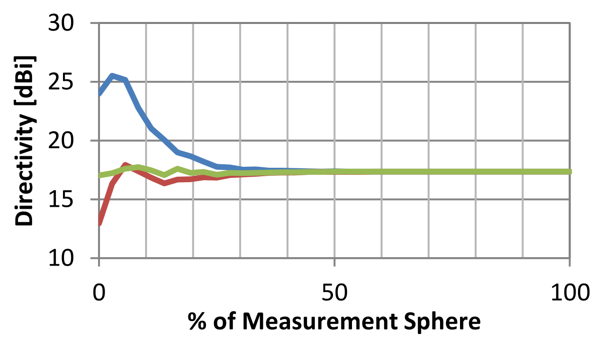

Fig.5: Comparison of acquisition without pre-conditioning (——), with pre-conditioning Method#1 (——), and with pre-conditioning Method#2 (——).

3. Further Experimental Results from NF Datasets

The use of the adaptive SNF method, using pre-conditioning, was studied using three different AUTs, a fan beam antenna, an isoflux antenna, and a base station antenna. The fan-beam antenna (FAN) is one whose main beam is much broader in one direction (azimuth in this case) than the other, and points towards the North Pole during acquisition. The isoflux antenna (ISO) is a low gain antenna pointing towards the North Pole during acquisition, but its main lobe maximum lies on a ring surrounding this direction. The base-station antenna (BSA) is one whose main beam is pointed away from the North Pole direction, and is instead in a direction -10 degrees in elevation and +25 degrees in azimuth. These three antennas were specifically selected for their unique patterns, in order to contrast the performance of the adaptive acquisition.

All three AUTs were acquired using Acquisition Rules #1 and #2 introduced in [1], along with pre-conditioning Method #1. Acquisition Rule #0, not mentioned in [1], is an idealized rule used only as a reference. A complete description of each rule is provided in [1], and a short summary for each is given below:

Rule #0 – A simulated rule, where the next NF data point selected is that with the next highest amplitude and so knowledge of the complete NF data set is required (Not a practical acquisition process).

Rule #1 – A growing surface starting at the North Pole of the sphere, scanning in ϕ and stepping in θ.

Rule #2 – An adaptive rule which performs a first scan in θ until a threshold is reached and then adds a band of samples around the first iteration as the subsequent iterations.

Additionally, three decision functions were defined in [1] and can be summarized as follows:

Decision Function #1 – Directivity obtained using the acquired near-field data, terminating once variation is less than ±0.1 dB

Decision Function #2 – The maximum pattern error, terminating when change between iterations is less than -40 dB.

Decision Function #3 – The first side lobe directivity obtained using the acquired near-field data, terminating once variation is less than ±0.1 dB (When Decision Function #3 is used, the position in space of the side lobe influences how much of the measurement sphere must be acquired before that parameter settles down to some stable value).

In order to compare the performance of different combinations of the above-mentioned acquisition rules and decision functions when interpolation Method #1 is used for pre-conditioning, the percentage of the measurement sphere is recorded when the listed decision function criteria have been attained. A summary of this performance for each antenna is given in Table 1. The best understanding of the behavior of the various pre-conditioning / acquisition rule / decision function combinations is gained by observing the progress of the overall adaptive SNF algorithm in time. This will be described during the conference presentation of this paper, using videos created for this purpose.

From the results displayed in Table 1, Acquisition Rule #2 seems to be the one best suited for a variety of AUTs, as in many cases the percentage of acquired measurement is either lower or similar to the other two acquisition rules. This is so even for those antennas whose pattern maxima point towards the North Pole or just slightly away from it. However, the difficulty with Acquisition Rule #2 is the selection of the threshold value for the initial iteration. Without having *a priori* knowledge about the AUT, it is difficult to choose an appropriate threshold value. If the threshold is too low, no ‘privileged’ direction will be selected, and Acquisition Rule #2 will behave just like Acquisition Rule #1. If the threshold is too high, most of the measurement sphere will be acquired in the first pass, thus cancelling any benefit from an adaptive technique. For that reason, when little is known about the AUT, it is simpler to use Acquisition Rule #1.

Maximum pattern error addressed by Decision function #2 is also interesting for automated decision, even though the value can oscillate during the acquisition. Selecting an appropriate threshold, say -30 dB, -40 dB or even -60 dB, can ensure that the overall FF pattern doesn’t change more than the selected value between iterations.

Table 1: Percentage of Measurement Sphere Needed for Termination of Adaptive SNF Technique Using Pre-Conditioning Method #1 and the Various Acquisition Rules and Decision Functions Indicated.

	Decision Function #1	**Decision Function #2**	**Decision Function #3**
FAN – Rule #0	41%	73%	37%
FAN – Rule #1	36%	58%	44%
FAN – Rule #2	39%	72%	22%
ISO – Rule #0	42%	61%	14%
ISO – Rule #1	44%	61%	35%
ISO – Rule #2	43%	62%	43%
BSA – Rule #0	22%	79%	52%
BSA – Rule #1	38%	61%	26%
BSA – Rule #2	25%	74%	34%

4.0 Concluding Remarks

Three pre-conditioning interpolation schemes were investigated in this paper for use with the adaptive SNF technique, with Method #1 determined to be the preferred scheme. The results for three acquisition rules and decision functions as applied with Method #1 to three different AUTs were presented. Of the three rules, Acquisition Rule #1 was found to offer the best overall test time reduction and is recommended when little information is available regarding the AUT.

During this study a varying degree of success was achieved using the adaptive SNF acquisition. However, it is important to realize that although in some instances the test time savings can be significant and in other cases it may be marginal, the worst case scenario will be equal to a full sphere acquisition, which is on par with the accepted norm for SNF testing today.

References

[1] V. Beaulé, D. A. McNamara, D. J. Janse van Rensburg, L. Shafai & S. Mishra, "Exploration of the Feasibility of Adaptive Spherical Near-Field Antenna Measurements", Proc. *34th Annual AMTA Symposium*, October 2012, Seattle, USA.

[2] D. J. Janse van Rensburg, D. A. McNamara & G. Parsons, "Adaptive acquisition techniques for planar near-field antenna measurements", Proc. *33rd Annual AMTA Symposium*, October 2011, Denver, USA.