Radiation Pattern Reconstruction from the Near-Field Amplitude Measurement on Two Planes using PSO

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Abstract. *The paper presents a new approach to the radiation pattern reconstruction from near-field amplitude only measurement over a two planar scanning surfaces. This new method for antenna pattern reconstruction is based on the global optimization PSO (Particle Swarm Optimization). The paper presents appropriate phaseless measurement requirements and phase retrieval algorithm together with a brief description of the particle swarm optimization method. In order to examine the methodologies developed in this paper, phaseless measurement results for two different antennas are presented and compared to results obtained by a complex measurement (amplitude and phase).*

Keywords

Near-field, radiation pattern, planar near-field scanning, amplitude near-field measurement, phase reconstruction, global optimization, particle swarm optimization (PSO).

1. Introduction

Standard antenna radiation pattern measurements have to be measured in their far-field region which could lie too far for electrically large antennas and complex antenna systems to be fitted within actual test range or an anechoic chamber. Measurement can then only be made in the near field. Near-field (NF) measurements provide a fast and accurate method of determining the antenna gain, pattern, polarization, beam pointing etc. Near-field antenna measurement methods, in contrast to conventional far-field methods, make use of a measuring probe in the radiating near-field region of the antenna under test (AUT). The far-field (radiation) pattern of the AUT must then be indirectly computed from the measurements made in a near-field region. For standard complex (amplitude and phase) planar near-field measurements, which is the most common NF technique for a low sidelobe antennas, a Fourier transform of the complex near-field data is required to obtain radiation pattern or other far-field antenna parameters. But standard NF measurement can be a very sensitive to the phase measurement errors. There are applications where an accurate phase measurement may not be practically achievable. For

example, in high frequency applications the accuracy of the phase measurement might be limited by the positional tolerances measuring probe. Moreover, the very high cost of vector measurement equipment limit accurate phase measurement at high frequencies.

Above mentioned limitations of a standard complex near-field measurement gives rise to the problem of retrieving the full complex field distribution from the knowledge of amplitude data alone. This problem has met with considerable interest and plenty of papers related to the phaseless near-filed measurement have been presented. However since almost all approaches rely more or less explicit on the minimization of an appropriate cost functional, they have to fight a serious drawback, presence of local minima on which the solution algorithm could converge. To reach the solution (global minima), the starting point of the minimization algorithm must lie in the region of the functional global minimum. At the moment available phase retrieval algorithms are based on local minimization methods and the problem of local minima convergence is bypassed for example by enlarging of the global minima convergence domain [1] or by using additional information of the AUT and/or by rough phase measurement in the near-field [2]. All these methods suffer by a large numerical complexity or a necessity of an additional information (rough phase measurement) which extend measurement time and instrumentation complexity.

In this paper we present a completely different phase retrieval method which does not suffer by the possibility of local minima convergence and its numerical complexity is relatively simple. The proposed method is based on a global optimization. Thus, no additional information about AUT or a starting point choice in a global minima region is not necessary to reach the right solution. The algorithm employ a new global optimization method called shortly PSO (Particle Swarm Optimization). This method has been developed just ten years ago and in 2002 was firstly applied to the electromagnetic problems. An implementation of the PSO, as a method to rough estimate of the global minima for a phase retrieval problem is presented here. Subsequently to reach global minima with sufficient accuracy a common Fourier iterative algorithm has been used [2].

Results obtained by applying the proposed algorithm to a set of measured data are given in Section 3. Two diffe-

rent antennas have been measured in order to illustrate the applicability and accuracy of the proposed phase retrieval algorithm.

2. Theory

The concept and setup of the phaseless planar near-field antenna measurement technique have already been extensively described in many publications. Therefore we just briefly remind it here. Planar near-field scanning system consists of two parallel scanning planes (Fig. 1). The scanning planes lie in different distances $z = z_1$ and $z = z_2$, with respect to a fixed reference system. Dimensions of the scanning planes have to be large enough to cover all significant radiated energy from the AUT [3]. Phaseless measurements are obtained at both scanning planes with respect to the AUT aperture plane (where the origin of the coordinate system is usually placed). The near-field amplitude data, on each of these scanning planes, is acquired in accordance with the sampling requirements [3], [7].
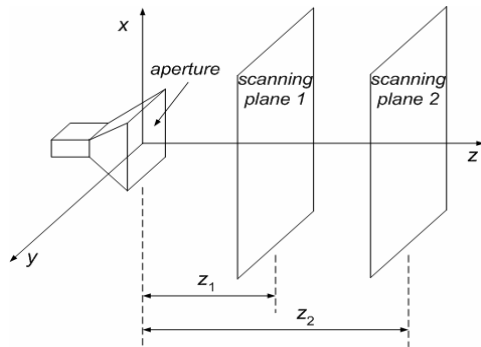
Fig. 1. Concept of the phaseless planar near-field measurement using two scanning planes

2.1 Phase Retrieval Algorithm

One of the main advantages of the presented algorithm (Fig. 2) is its low computational effort required for its use in a numerical procedure and a very simple implementation (algorithm can be written in a few lines of a program code).

Firstly, random initial guess of the complex (amplitude ad phase) field distribution on the AUT aperture is made. Subsequently, to this guess samples a zeros are added to get the same extension as the scanning surfaces have. After this operation is the initial guess of the electric field aperture distribution transformed (using the fast Fourier transform – FFT) to the plane wave spectrum and multiplied by the propagation coefficient to the plane of the first and the second scanning surface. At this point both, PWS at the first and the second scanning surface, is transformed back (using inverse FFT) to the electric field distribution on the first and the second plane respective (Fig. 2).

In next step the computed modulus of the electric field distribution on the first (second) scanning surface is compared with a measured amplitude distribution at the first (second) scanning surface according the following cost function

$$F = \sum_{i=1}^{N}\sum_{j=1}^{N} \frac{\left[\left| E_1(i,j)\right|^2 - \widetilde{M}_1(i,j)^2\right]^2}{\widetilde{M}_1(i,j)^2} +$$
$$+ \sum_{i=1}^{N}\sum_{j=1}^{N} \frac{\left[\left| E_2(i,j)\right|^2 - \widetilde{M}_2(i,j)^2\right]^2}{\widetilde{M}_2(i,j)^2} , \tag{1}$$

where $E_1(i,j)$ and $E_2(i,j)$ is the computed complex intensity at the point i, j on the first and the second scanning surface, and $\widetilde{M}_1(i,j)$ and $\widetilde{M}_2(i,j)$ is the measured amplitude at the point i, j on the first and the second scanning surface.

The cost function (1) product represents an error that is subsequently minimized by using the global optimization PSO algorithm.
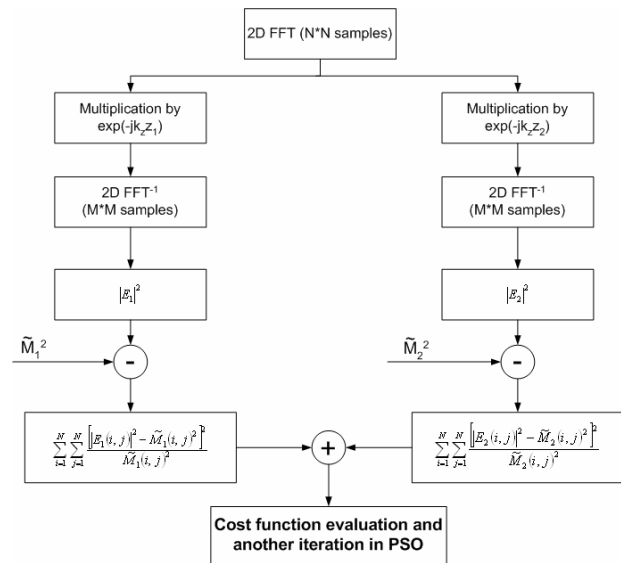
Fig. 2. Phase retrieval algorithm – cost function evaluation.

2.2 The PSO Algorithm

The PSO method has been developed by Kennedy and Eberhart in 1995 as an analogy to the bees swarm behavior [4]. To understand how the PSO algorithm works, imagine a swarm of bees in a field. Their goal is to find the location with the highest density of flowers. Without any knowledge of the field a priori, the bees being in random locations with random velocities looking for flowers. Each bee can remember the locations that it found the most flowers, and somehow knows the locations where the other bees found an abundance of flowers. Torn between returning to the location where it had personally found the most flowers, the ambivalent bee accelerates in both directions altering its trajectory to fly somewhere between the two points depending on whether nostalgia or social influence dominates its decision. Along the way, a bee might find a place with higher concentration of flowers than it had found previously. It would then be draw to this new location as well as the location of the most flowers found by the whole swarm. Occasionally, one bee may fly over a

place with more flowers than had been encountered by any bee in the swarm. The whole swarm would then be drawn toward that location in additional to their own personal discovery. In this way the bees explore the field: overflying locations of greatest concentration, then being pulled back toward them. Constantly, they are checking the territory they fly over against previously encountered locations of highest concentration hopping to find the absolute highest concentration of flowers. Soon, all the bees start to swarm around the point with the absolutely highest flower concentration.

In attempting to model this behavior, Kennedy and Eberhart developed Particle Swarm Optimizer – PSO. Then in 2002, their original algorithm has been modified to be suitable also for electromagnetic problems [5]. A more detailed description of the PSO algorithm can be found in [5]. Here we focus our aim to PSO implementation into a phase retrieval algorithm. Flow chart of the PSO algorithm used for a phase retrieval problem is depicted below (Fig. 3)
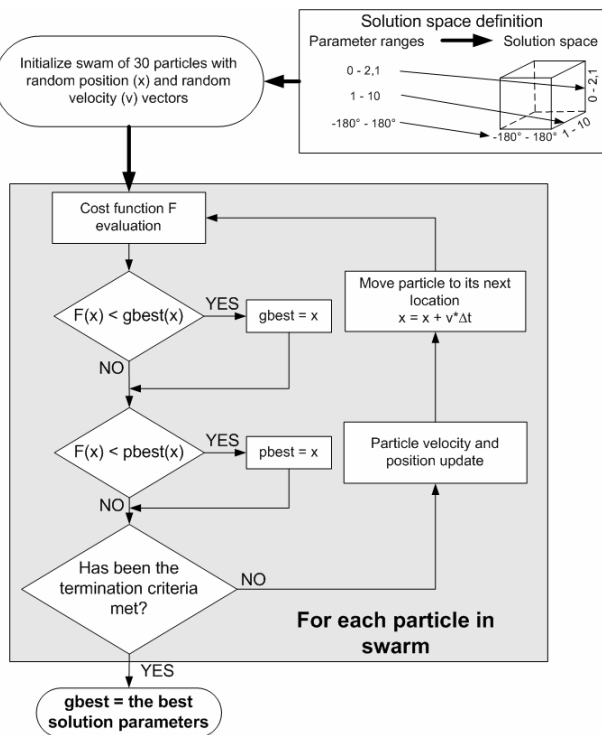

Fig. 3. Flow chart of the PSO algorithm.

First of all we have to define the solution space. Since our solution is a complex intensity distribution on the AUT aperture, the solution space has just two dimensions, amplitude and phase. Range for phase is evident (-180°; 180°), there is no problem with its definition. But range for amplitude has to be defined with more attention. Minimum is clear; amplitude can not be below zero. In the case of maximum, we have found that is sufficient if we use the greatest measured amplitude on the first canning surface as an upper limit in range for amplitude. Now we have to define main PSO parameters. Experimentally has been found that the following combination is the most suitable for pha-

se retrieval problems: 30 particles (bees) in the swarm; absorbing walls and velocity with constant inertial weight [5].

At this moment an optimization process can be started. At the beginning all particles are randomly spread out in the whole solution space with random velocities and random directions of exploration. In the next step a value of the cost function (1) is evaluated for each particle. If the value is greater than the value from the previous step for that particle (*pbest*), or for the whole swarm (*gbest*), then the appropriate location is replaced with the current location (more accurate estimate of the solution) and velocity is updated. Once the velocity has been determined it is simple to move the particle to its next location. This process is applied to each particle in the swarm and the whole process is repeated starting with new evaluation of the cost function (Fig. 3). Repetition of this cycle is continued until convergence starts to stagnate or a maximum iteration number has been reached. Then, the solution is stored in *gbest* [5].

3. Measurement Results

The main aim of this paper is to demonstrate the applicability of the PSO algorithm in the phase retrieval problem as a method for accurate estimation of the starting point (in the global minima region) for other local optimizer. To find global minima precisely a common iterative process has been used [2]. This iterative process has been started with the initial guess calculated with PSO. To illustrate successful implementation of the PSO into phase retrieval problem measurement result for two different antennas are presented.

Fig. 4. Measurement setup in the case of horn antenna.

3.1 Horn Antenna T1-R100

The phase retrieval algorithm has been applied to phaseless planar near-field measurement data for the horn

antenna of Fig. 4. This antenna operates at 12.4 GHz with horizontal polarization. Amplitude and phase were measured on each plane so that phase retrieval results could be compared with standard complex near-field measurement. Measurement planes were placed to the distance of 60 mm and 70 mm respective from the horn antenna aperture. Both measurement planes had same dimensions of 400×400 mm. Near-filed data were collected in a uniformly spaced rectangular grid of 41×41 points covering the whole scanning plane.
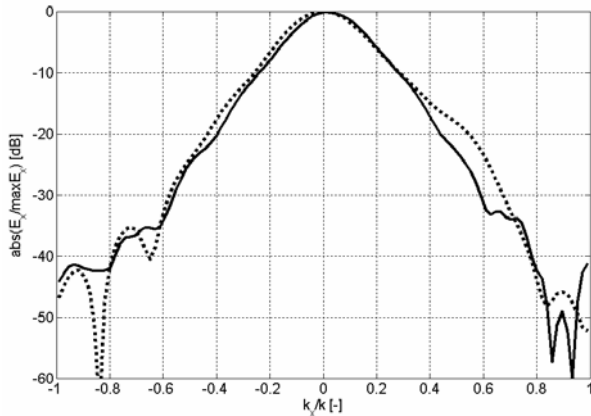
Fig. 5. Radiation pattern of the horn antenna in E-plane (bold – standard near-field measurement, dotted – phase retrieval).

The phase retrieval algorithm was initiated with a random estimate of field in the horn antenna aperture. A 128×128 point FFT was used in the phase retrieval algorithm. The comparison of the H-plane and E-plane patterns of the horn antenna obtained from phase retrieval algorithm and from processing utilizing the measured near-field amplitude and phase at the first scanning plane are shown in Fig. 5 and Fig. 6, respectively. Very good agreement between reconstructed pattern from the phaseless data and the pattern obtained from complex measurement has been gained for both, E-plane and H-plane.
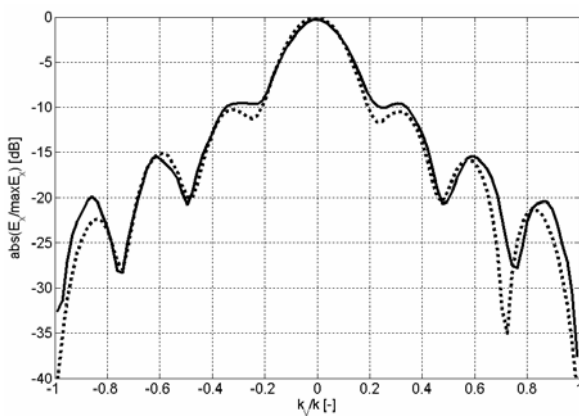

Fig. 6. Radiation pattern of the horn antenna in H-plane (bold – standard near-field measurement, dotted – phase retrieval).

3.2 Dish Antenna

The phase retrieval algorithm has been applied to phaseless planar near-field measurement data for the dish antenna of Fig. 7. This antenna operates at 14.4 GHz with horizontal polarization. Again, amplitude and phase were measured on each plane so that phase retrieval results could be compared. The measurement planes were placed to the distance of 268 mm, 298 mm respective from the dish antenna aperture (edge of the reflector).
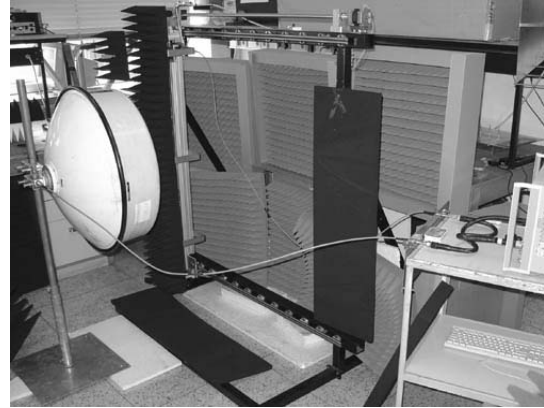

Fig. 7. Measurement setup in the case of dish antenna.

Both measurement planes had same dimensions of 800 × 800 mm. Near-filed data were collected in a uniformly spaced rectangular grid of 81×81 points covering the whole scanning plane.
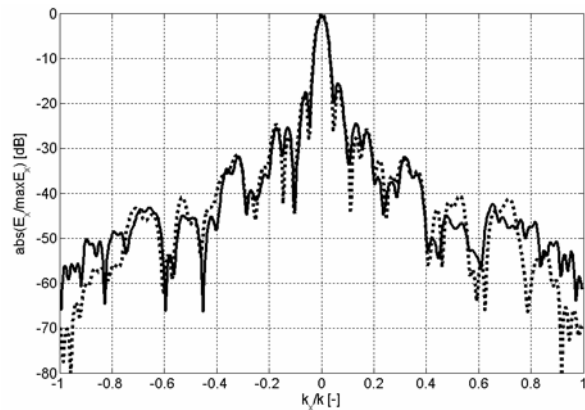

Fig. 8. Radiation pattern of the dish antenna in E-plane (bold – standard near-field measurement, dotted – phase retrieval).

The phase retrieval algorithm was again initiated with a random estimate of field in the dish antenna aperture. In this case a 512×512 (for better spectral resolution) point FFT was used in the phase retrieval algorithm. A comparison of the H-plane and E-plane patterns of the dish antenna obtained from phase retrieval and from processing utilizing the measured near-field amplitude and phase at the first scanning plane are shown in Fig. 8 and Fig. 9, respectively. Again, very good agreement between reconstructed pattern from the phaseless data and pattern obtained from complex measurement has been gained for both, E-plane and H-plane.

4. Conclusion

A new phase retrieval algorithm utilizing global optimization PSO and common iterative process has been pre-

sented. Proposed algorithm is very robust and simpler than comparable algorithms available. The algorithm does not require any initial guess in the global minima region and no additional information are needed. The application of the described algorithm to two antenna phaseless measurement examples was presented. The far-field patterns from the phase retrieval algorithm were shown to have a very good agreement with results produces using measured complex (amplitude and phase) near-field.
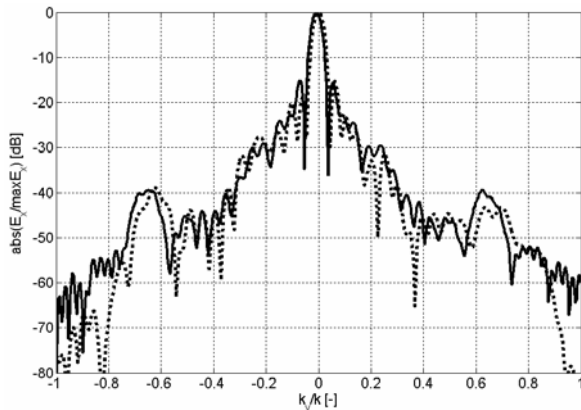

Fig. 9. Radiation pattern of the dish antenna in H-plane (bold – standard near-field measurement, dotted – phase retrieval).

Acknowledgements

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